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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

DECEMBER 2023

Andromeda's Riotous Past

Page 12

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North-right composite image of M31 with its galactic friends

PHOTO: SEAN WALKER / MDW SURVEY

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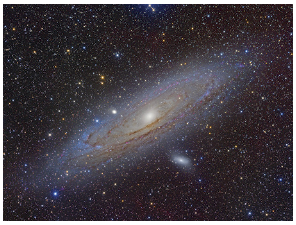
Great Lengths

IN HIS COVER STORY on page 12, Ken Croswell mentions in passing the Andromeda Galaxy's proximity to us — "it's only 2.5 million light-years from Earth," he writes. *Only* 2.5 million light-years?! One light-year is about 9.5 million million kilometers (6 trillion miles). Multiply that by 2,500,000 and you get, well, brain fog. In what universe could 2.5 million light-years possibly be considered close?

Ours. Apropos of that, it's worth reminding ourselves now and then just how staggering the distances to even "nearby" celestial objects truly are. And how quickly our ability to envisage those gaps with any verisimilitude falters.

To get some sense of the distance to Andromeda, let's start small. The distance to the nearest star beyond the Sun, Proxima Centauri, is about 4.2 light-years. (Or about 1.3 *parsecs* — see Beginner's Space on page 74 for more on that term and why professional astronomers prefer it.) Sounds reasonably nearby, right? Actually, that's nearly 40,000,000,000,000 km away, or close to 267,000 times the average Earth–Sun distance. If the Voyager 1 spacecraft, which is speeding away from our solar system at about 17 km/s, were heading to Proxima instead of just out into interstellar space, it would take over 74,000 years to reach the star. We'd have to multiply that eon of time by 2.5 million to get the years Voyager would need to attain just the next galaxy over.



▲ Our closest major neighbor: the Andromeda Galaxy

MASIL IMAGING TEAM

Given how far away Andromeda is, it's amazing that we can see it with the naked eye from a dark-sky site. But with large telescopes, we can observe galaxies that lie over a *billion* light-years away. In his article on page 18, amateur Jimi Lowrey describes the 12 most distant galaxies in the *NGC* and *IC* catalogs that were discovered visually (most, remarkably enough, in the 1800s). Observe these yourself, as Lowrey has, and you join an elite bunch — the billion-light-year club. Forget trying to grasp the stretch that photons, zipping along at roughly 300,000 km/s, cover in a billion years.

Then there are the galaxies the James Webb Space Telescope is detecting. Light left some of those well over 13 billion years ago, within a few hundred million years of the Big Bang. With the universe's expansion, it's hard to say just how far such early galaxies lie, but it's as mind-boggling as the notion that in all that insanely vast distance, nothing blocks that light from reaching JWST.

Contemplating such temporal and spatial scales can be draining. Better to just accept that the light we see from Andromeda, for instance, left that galaxy 2.5 million years ago and traveled a ginormous distance to reach us. Only then can one say, with equanimity, that it's "only 2.5 million light-years from Earth."

Peter

Editor in Chief

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AAS
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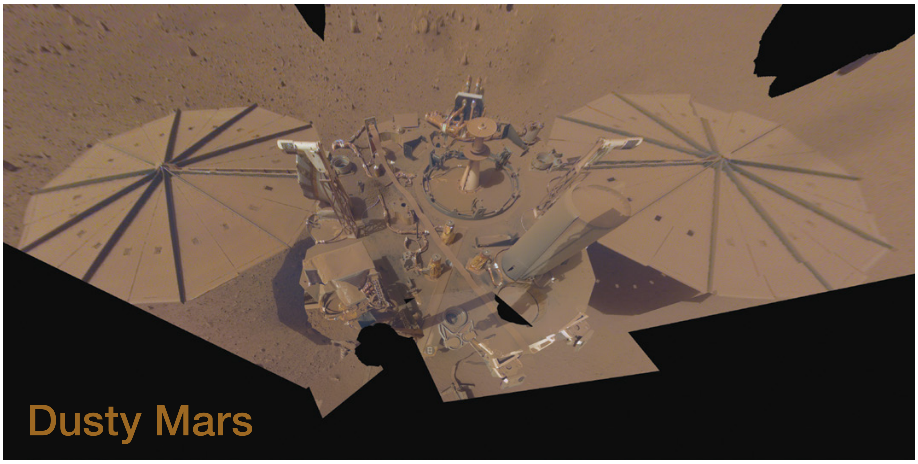
Dusty Mars



▲ NASA's Insight lander captured this final selfie showing the heavy coat of red dust that would later spell the end of its four-year mission.

Two questions came to mind after reading Javier Barbuzano's excellent article "Shake, Rattle, and Roll" (*S&T:* Aug. 2023, p. 12) on the Mars Insight lander. Dust covered the lander's solar panels, and the mission ended after four years. Bruce Banerdt, the principal investigator, said it was like losing a friend and colleague. Insight was still doing its job providing valuable data on the planet's interior structure up to that point, even though the mission was only expected to last two years. What dust-clearing techniques is NASA working on, since this is a well-documented problem? Having longer-term instruments would be a huge benefit in planning future missions and studying the planet.

Second, the lander's seismometer detected two meteorite impacts on Mars in 2021, and the Mars Reconnaissance Orbiter found craters up to 150 meters (500 feet) in diameter. How does NASA plan to deal with these risks in future manned missions? Are those risks just added to the list of "death at your doorstep" in space?

Stephen Keedy
Lebanon, Connecticut

Camille Carlisle replies: *Regarding the dust, I've asked Mars mission scientists the same thing, but I haven't heard of any dust-mitigation technology being developed by NASA for landers and rovers. Nor do I think we'll see any soon: So far, the weight and cost associated with installing such tech (would we have to boot off a scientific instrument to make space?) has overridden potential benefits. The philosophy remains, "let the wind clean it for us."*

To your second question, the danger from impact is pretty low. A 2013 study estimated that the average square kilometer of Martian surface would be hit by something that could make at least a 4-meter-wide crater maybe every 600,000 years. The two impacts we discussed in the article are far apart — so far that we couldn't put them both on our map on pages 14–15, because it would have necessitated extending the map eastward by at least 40° longitude.

The impact risk is higher on Mars than it is on Earth, because our denser atmosphere shields us better. But still, I'm told it's not a major concern.

Arguably Accurate

The article "Shake, Rattle, and Roll" is marvelously informative and interesting. However, there is a moment of unintentionally humorous hyperbole when the author writes that "Mars is arguably the most studied planet in the solar system . . ."

I don't think so!

Joel Marks
Milford, Connecticut

Camille Carlisle replies: *Ha! That statement was intentional and carefully considered. The author and I discussed it during the fact check — I literally wrote, "Let's add 'arguably' as a caveat, since someone may well complain that we're overlooking Earth." Certainly, we have much better seismic data on Earth, and we've spent a lot of time poking around our planet's nooks and crannies. But our satellite maps of Mars are higher resolution than our maps of Earth's seafloor, and we know far more about atmospheric escape at Mars than we do for any other planet, including Earth.*

So, in terms of studying Earth as a planet, one can make the case that it doesn't beat out our study of Mars. But, of course, this is why we said "arguably" — because we can reasonably disagree.

Astrophotography: Why Not?

Tony Puerzer's excellent article "Astrophotography: Why Bother?" (*S&T:* Aug. 2023, p. 54) details many important reasons for pursuing amateur astrophotography. For me, astrophotography opens a window to explore the nature of the celestial objects imaged and the history of how our knowledge of the complex and beautiful universe has developed. Astrophotography enables me to see things that are not available if I limit myself to visual observation. A humbling awe comes with digitally recording a supernova from a distant galaxy or capturing a star-forming nebula in our own galaxy. We are so fortunate to have readily available tools to take images of these incredible objects. What better way to immerse oneself in the wonders of the universe than a deep dive into astrophotography?

Jim Case
Chino Hills, California

Keeping It Simple

Great insight from Rod Mollise in his article "More Better Gooder" (*S&T:* Aug. 2023, p. 84), which is an invaluable piece of wisdom. I use the word "insight" precisely. His comment "I've learned to see again . . ." — after decades of his obsession with more "toy" power in his viewing instrumentation — is the point.

The first deep-sky object I found by myself in the 1980s with my new Meade 20×80 binoculars remains unforgettable.

INSIGHT SELFIE: NASA / JPL-CALTECH; SAD EARTH: DKDESIGNZ / SHUTTERSTOCK

I've seen many photographs of M7 since then, but there is nothing like "simple," live viewing. The image has stayed in my mind. The same was true when I first found M41 with binoculars. And even more so when, unlooked for, I happened to discover M38, M36, M35, and M37 — clusters I didn't even know about — appearing like a stairway to heaven, with a thrill that is difficult to express. Observation becomes contemplative joy.

Clyde Glandon
Tulsa, Oklahoma

Calling All Historians

Thank you so much for Dennis di Cicco's excellent article "Stellafane Turns 100" (*S&T:* Aug. 2023, p. 60) about the centennial celebration of the Springfield Telescope Makers this year. At the 2023 Stellafane Convention, we featured numerous historical artifacts and photos, but we are seeking to expand our collections from Stellafane's past. We have a special request for the astronomy community to help us with our ongoing Stellafane history project. If anyone has old photos or other artifacts from Stellafane's past that they would like to share with us, they can reach out to us at **history@stellafane.org**. We look forward to seeing old friends and meeting new ones on Breezy Hill throughout the year, just as Russell Porter and his fellow explorers of the universe did 100 years ago.

Cecilia Detrich
Vice President
Springfield Telescope Makers
Nahant, Massachusetts

FOR THE RECORD

- In "The Past and Future of Star Names," the name Achernar (*S&T:* May 2023, p. 31) comes from *akhir al-nahr* (River's End).
- In "What Is a Spectrum?" (*S&T:* Sep. 2023, p. 74), the base of a candle flame isn't bluer because it's hotter. While the orange part of candle flames can indeed be treated as blackbody emitters, the blue base of a flame comes from chemical reactions that emit light at specific wavelengths and is thus not a blackbody.
- In "What Is an Aurora?" (*S&T:* Oct. 2023, p. 74), we wrote that Mercury is the only planet without aurorae. A day after we went to press, a new research paper brought to our attention that this is not a straightforward matter. Particles accelerated within Mercury's magnetosphere do indeed travel down field lines and interact with the planet in a way that reflects the magnetosphere's structure. However, the particles interact with the surface, not an atmosphere, creating X-ray fluorescence instead of exciting or ionizing atoms. Thus, while different, the phenomenon is closely analogous to terrestrial aurorae and can be called an "aurora" for simplicity's sake.

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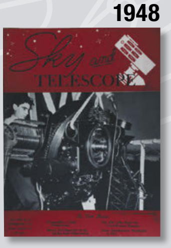
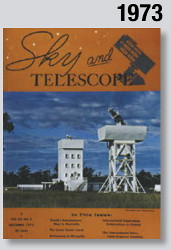
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1948



1973



1998

December 1948

Postwar Normalcy "The International Astronomical Union, after an interruption of 10 years, again had a full session, in Zurich, Switzerland, with nearly 40 international commissions in action. New commissions on microwave research, close binaries, and astronomical history were set up.

"The bureau on variation of latitude made an excellent report on the wandering of the earth's poles. In the operation of its five collaborating observatories, in America, Italy, Russia, and Japan, the bureau is a sort of United Nations of geodesy. Dr. Bernard Lyot, of the Pic du Midi Observatory in France, reported on his continuing magic touch in coronagraphy; and the Moscow astronomers revived the war-interrupted Prager-Schneller handbook of variable stars."

Harlow Shapley was listing astronomical highlights of 1948.

December 1973

Moon Mystery "[A] white patch was noted in 1823 but was misinterpreted as the floor of a crater six to 11 kilometers across. In 1866 the astronomer Julius Schmidt announced that the crater had vanished, being replaced by a white spot surrounding a craterlet only about 500 meters across. Reports of still other apparent changes followed, and Linné became one of the most famous 'problem' craters on the moon. . . .

"Apollo 15 photographs, which reveal Linné as an extremely fresh but otherwise quite ordinary impact crater, [ended the controversy]. There is no evidence that this crater has ever changed substantially in shape. Totally absent is the rim asymmetry or concentricity which would be expected if, by coincidence, a second impact had been scored directly on the alleged larger crater observed before 1866. . . .

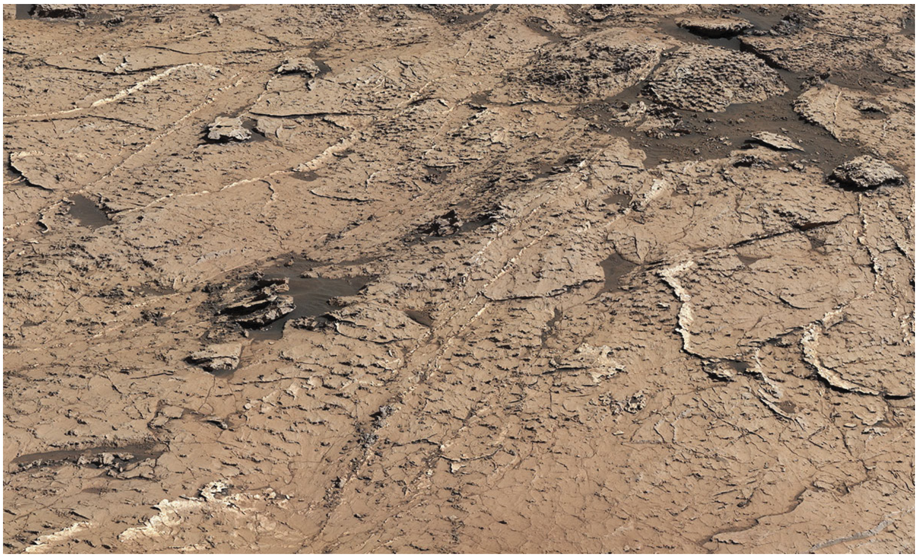
"Evidently, optical effects were responsible for the enigmatic changes reported in Linné, an apt testament to the perils of interpreting visual lunar observations . . ."

R. Pike (U.S. Geological Survey) adds that Linné is 2.45 km across.

December 1998

Jovian Rings "Since its discovery by Voyager 1 in 1979, the ring system of Jupiter has been a puzzle. Virtually unobservable from Earth, the diaphanous disk is dominated by smoke-size motes spaced 30 meters apart on average. . . . Particles this small are at the mercy of forces that drag them into Jupiter's atmosphere or out of the ring plane. Thus they must be replenished constantly — but from where?

"Astronomers now know: the dust is being blasted off the surfaces of the planet's four innermost moons. Cornell scientists Joseph A. Burns, Maureen E. Bell, and [Joseph] Veverka say the ring particles are generated in profusion when micrometeorites strike the satellites' surfaces at velocities near 30 kilometers per second."



▲ Curiosity's MastCam captured this panorama of mud cracks on Mars. Polygonal shapes form after multiple wet-dry cycles.

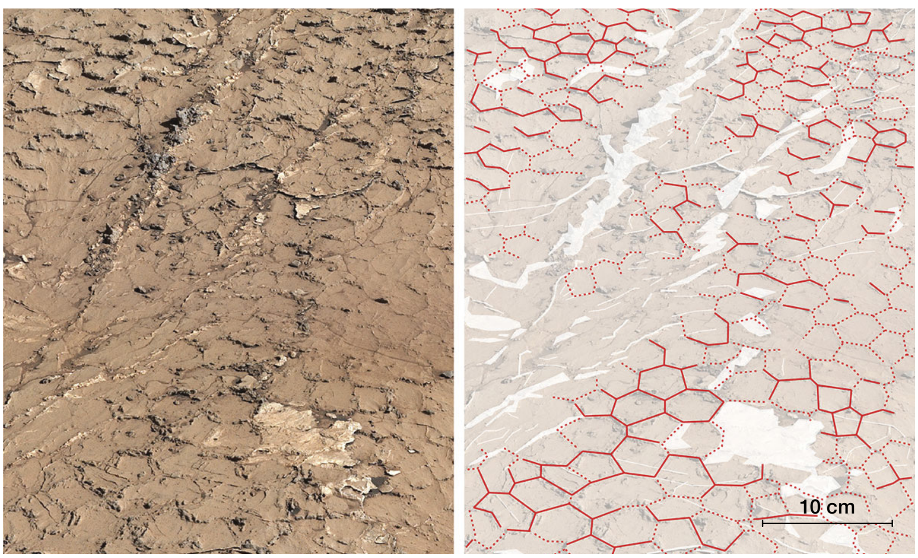
SOLAR SYSTEM

What Mud Cracks Mean for Life on Mars

PLANETARY SCIENTISTS analyzing data from NASA's Curiosity rover have spotted evidence of sustained wet-dry cycles on early Mars. The find is intriguing given that similar climatic cycles have long been linked to the advent of life on Earth.

In the August 10th *Nature*, a team led by William Rapin (University of Toulouse, France) describes mud cracks that Curiosity encountered in 2021. "These particular mud cracks form when wet-dry conditions occur repeatedly — perhaps seasonally," Rapin says.

The rover team found the cracks while ascending Mount Sharp, the central peak that towers 5.5 kilometers (3.4 miles) over Gale Crater. The rover examined cracks it encountered near a rock nicknamed "Pontours," which lies in a transitional region between a clay-rich layer and another layer enriched with salty sulfates. Clay-rich layers tend to form in water, whereas salty layers emerge when water dries up.



▲ A close-up of mud cracks alongside the same image with the polygonal shapes outlined in red. The hexagons average 4 centimeters (1.5 inches) across.

As the Martian mud dried out, it shrank and fractured into T-shape junctions, which repeated wet-dry cycles softened into a Y shape. Where several of these junctions meet, they create the distinctive patchwork of polygonal cracks that Curiosity saw.

The mud cracks date to the Noachian–Hesperian transition 3.8 to 3.6 billion years ago. The pattern may have emerged as Gale Crater was repeatedly flooded and/or as ground water swelled upwards. Rapin and his team think that a salty sulfate crust running along the cracks' edges has preserved their shapes over billions of years.

"We know that wet-dry cycles can drive chemical reactions to obtain the building blocks of life," says Sidney Becker (Max Planck Institute of Molecular Physiology, Germany), who was not involved in the research. "Finding those conditions on Mars is an exciting discovery." That's because as the water begins to dry up, the concentration of soluble ingredients in the remaining water increases. This heightened concentration can then boost chemical-reaction rates and raise the chances of constructing the complex molecules on which life relies.

However, Becker also points out that, even if there was wet-dry cycling, we don't know if Mars had the right atmospheric or mineral ingredients for life. And even meeting those requirements is no guarantee. "The conditions needed for the origin of life might be different to the ones that actually create the needed building blocks," Becker says.

If wet-dry cycles did help create ancient life on Mars, they could also have worked against it. "The conditions to sustain life over a long period of time again could be very different," Becker says. "Since first life was likely very fragile, wet-dry cycling might have caused too much external disturbance." Life's maker could ultimately have been its destroyer.

So, while these cracks are an important piece of the puzzle, we are still a long way from being able to say whether ancient Mars hosted life.

■ **COLIN STUART**

NASA / JPL-CALTECH / MSSS / IRAP (2)

BLACK HOLES

The Hyades Might Harbor Black Holes

THE NEAREST BLACK HOLES might be hiding around the corner, astronomically speaking — lurking in the Hyades, a 650 million-year-old open star cluster 155 light-years away in Taurus, the Bull. If that's true, it would shatter the previous record for nearest black hole by a factor of 10 (*S&T:* Aug. 2021, p. 8).

Gravitational interactions between stars in the Hyades would have caused more massive objects, including black holes, to sink toward the center. Less massive stars would in turn gain kinetic energy and end up on wider orbits, effectively spreading out the cluster.

Working with the latest astrometry data from the European Space Agency's Gaia mission, Stefano Torniamenti (University of Padova, Italy) and colleagues conclude that the Hyades is about 30% larger than expected if the cluster had never possessed black holes. Computer simulations with two or three black holes residing in the cluster

▲ The Hyades star cluster, a group of thousands of stars 155 light-years away in Taurus

for hundreds of millions of years better match the observations, the team writes in the September *Monthly Notices of the Royal Astronomical Society.* (There is, however, no guarantee the black holes didn't leave the cluster more recently.)

Black holes in the Hyades aren't completely unexpected: They'd come from the most massive stars, which would go supernova after just a few million years. The surprising thing, according to team member Mark Gieles (University of Barcelona, Spain), is that the long-term presence of a couple of black holes has had such a strong effect on the cluster's structure and motions.

Finding black holes in the Hyades would have implications beyond breaking proximity records. It would also suggest that whatever "kick" newborn black holes receive, it can't be very much for at least some of them or they'd all have escaped the cluster.

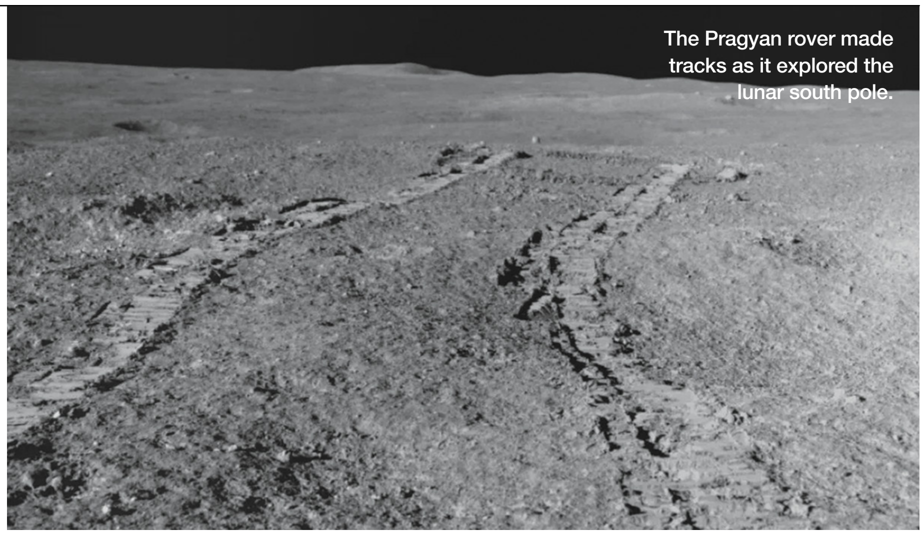
At the same time, Pavel Kroupa (University of Bonn, Germany), who wasn't involved with the research, notes that under an alternative theory of gravity, known as modified Newtonian dynamics, the same data would be consistent with no black holes.

Independent confirmation is vital, but that might be easier said than done. According to team member Zephyr Penoyre (University of Cambridge, UK), direct evidence of those black holes will be difficult to find. Their search for binary systems with one massive companion has so far turned up empty.

■ GOVERT SCHILLING

SPACE

Chandrayaan 3 Lands on the Moon; Luna 25 Crashes



The Pragyan rover made tracks as it explored the lunar south pole.

INDIA'S CHANDRAYAAN 3 successfully touched down near the Moon's south pole on August 23rd. Prime Minister Narendra Modi called the day "historic" for the nation, as India is now the fourth nation to conduct a controlled landing on the Moon. Russia's Luna 25, on the other hand, crashed on the lunar surface just four days before.

Chandrayaan 3 landed near the Manzinus U Crater in the south polar region on the lunar nearside, making it the first probe to explore the lunar south pole. The Vikram lander then deployed the six-wheeled Pragyan rover, to explore the surrounding terrain. Both lander and rover are equipped with scientific instruments to collect data on the plasma density above the surface, surface composition, and seismic activity. The solar-powered rover entered sleep mode for the two-week lunar night on September 2nd.

Russia almost beat India to the lunar south pole, but a failed orbital maneuver on August 19th caused the Luna 25 lander to crash instead, falling into the Pontécoulant G Crater. Luna 25 had been scheduled to land on August 21st. That crash followed several recent failures, including ispace's Hakuto-R lander earlier this year as well as the Israeli Beresheet lander and India's Chandrayaan 2 lander, both of which crashed on the Moon in 2019. Chandrayaan 3 built off of lessons learned from Chandrayaan 2's collision, including several changes to the lander configuration.

■ DAVID DICKINSON

HYADES: MAURICE TOET / WWW.MAURICETOET.NL; LUNAR TRACKS: INDIA SPACE RESEARCH ORGANIZATION

STARS

A Jekyll-Hyde White Dwarf

ASTRONOMERS HAVE FOUND a bizarre, two-faced white dwarf: one side hydrogen, the other helium.

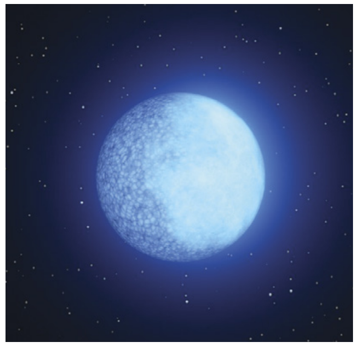
White dwarfs are the dense embers left behind when Sun-like stars die. The atoms in these erstwhile stellar cores separate by mass, the heavier stuff sinking and the lighter stuff rising to the surface. Since hydrogen is the lightest element, it winds up on top, with helium underneath.

But sometimes when a white dwarf cools down from its initial blaze (more than 100,000 kelvin) to a slightly less startling 35,000K, convection in the helium layer begins to dilute the overlying hydrogen. Eventually, the white dwarf continues its slow chill-out wrapped in a helium blanket.

But helium doesn't conquer at once. The newfound ZTF J203349.8+322901.1 may be an extreme example of this transition in action.

Ilaria Caiazzo (Caltech) and others discovered the object using the Zwicky Transient Facility. Follow-up observations revealed something odd: The dwarf appeared to vary in both brightness and composition as it spun around every 15 minutes. When the brighter side pointed at Earth, the team detected only hydrogen in the dwarf's spectrum; the other side showed only helium.

Reporting the find in the August 3rd *Nature*, Caiazzo and colleagues emphasize that they don't know for sure why the white dwarf — which they've nicknamed Janus for the two-faced Roman god of transition — looks this way. But they think the reason has to do with the object's magnetic field.



◀ Artist's illustration of Janus, a two-faced cinder of a star that appears to have one side of hydrogen and the other of helium

If localized to part of the surface, a magnetic field could easily choke convection in the area, preventing mixing. Conversely, where the field is weaker, helium could still ride convection to the surface. Alternatively, a magnetic field could suppress gas pressure and density over part of the surface, forming an "ocean" of hydrogen.

Either way, invoking magnetism is "perfectly reasonable," says Alexandros Gianninas (Connecticut College), who has studied similar, though less extreme, white dwarfs in transition.

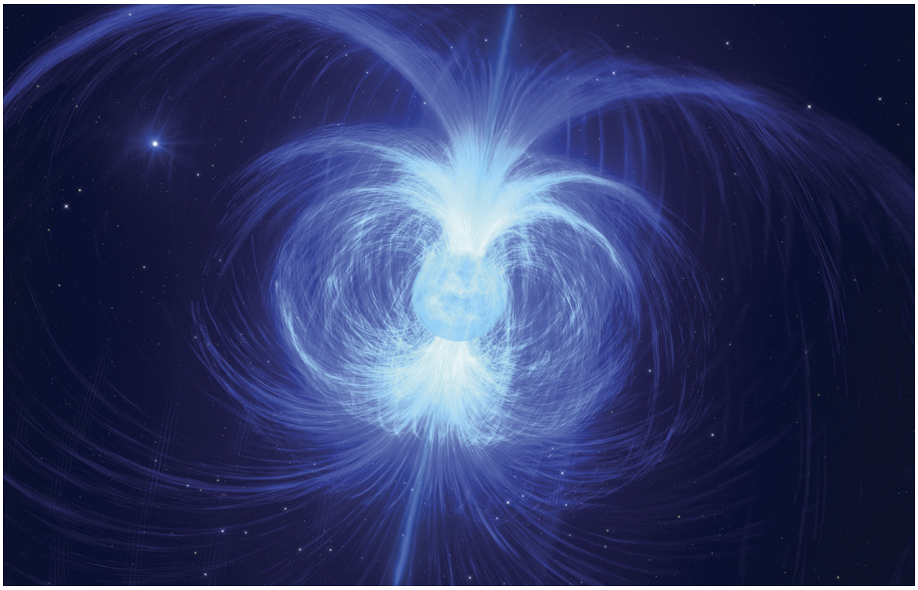
The changeover won't last forever, though. Eventually, as J20233 cools, convection will strengthen and the object will become a nondescript, helium-sheathed white dwarf.

■ CAMILLE M. CARLISLE

Some 1,400 light-years away in the southern constellation of Vela, the Sails, is a dark nebula dense with dust that blocks out background stars. With the James Webb Space Telescope (JWST), astronomers can see through and into this cloud (seen here in ethereal blue), revealing a pair of forming stars known as Herbig-Haro 46/47. Discovered in 1977, Herbig-Haro 46/47 has served as one of the prototypes of this unique celestial phenomenon ever since. The orange diffraction spikes point to the protostars' central location. The dense disk of dust and gas that feeds them isn't directly visible but is apparent by its shadow, cast as two dark cones above and below the stars, seen between the spikes. While huge masses of dusty gas feed the still-growing stars, it's the paltry plasma speeding away from the center that dominates the image. These jets provide an outlet for the angular momentum of the inward-spiraling gas in the disk, so they are key both to maintaining the stars' growth and, for astronomers, to understanding it.

■ MONICA YOUNG

TWO-FACED WHITE DWARF: K. MILLER / CALTECH / IPAC; JWST IMAGE OF STELLAR JETS: NASA / ESA / CSA; IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI), ANTON M. KOEKEMOER (STSCI)



STARS

Strange Star Is a Powerful Magnet

▲ This artist impression shows the powerfully magnetic star HD 45166. The magnetic field traps particles blowing away from the star, enshrouding the star in a gaseous shell.

THERE'S AN ODD STAR 3,300 light-years away in the southern constellation of Monoceros, the Unicorn.

The star, known as HD 45166, appears to be in the *Wolf-Rayet* class. These helium-dominated stars blow away violent winds, leaving a distinctive signature in the star's spectrum. However, while most Wolf-Rayet stars hold more than eight Suns' worth of mass, this one has much less than that. Its low mass could be explained if this peculiar object formed via a collision of two lower-mass stars. But if that were the case, it shouldn't be able to make such a strong wind — and its spectrum says it is.

Tomer Shenar (University of Amsterdam) and colleagues used new observations as well decades of older data from a plethora of telescopes to examine the star's magnetic field, publishing the results in the August 17th *Science*.

Most stars actually aren't all that magnetic — an average area on the Sun, for example, has a field of only about 1 Gauss, about twice the strength of Earth's surface field. A tenth of massive stars are more magnetic, though, and these are likely the progenitors of the extreme magnetism found in *magnetars*, neutron stars with fields 100 trillion times stronger than the Sun's.

Shenar's team thus used an instrument on the Canada-France-Hawaii Telescope to look for a magnetic field's chemical fingerprints in the spectrum of HD 45166. And they found it — a field of a whopping 43,000 Gauss. "One-thousand-Gauss magnetic fields are pretty rare amongst massive stars, so 43,000 Gauss is really off the chart," says Paul Crowther (University of Sheffield, UK), who was not involved in the *Science* study.

The star's powerful magnetic field as well as other data point to its origin in a stellar merger. The strong field now traps outflowing material, making its weak wind appear stronger than it is. "This paper resolves a long-standing puzzle about HD 45166, since it has been recognized as an oddity amongst Wolf-Rayet stars," Crowther says.

Eventually, this star will collapse into a neutron star, and its magnetic field will strengthen as it does so. The star may then become a magnetar. However, Crowther isn't sure of that destiny: "Lots of complex physics happens during a supernova explosion," he says.

■ MONICA YOUNG

ESO / L. CALÇADA

IN BRIEF

ALMA Reveals Planet Beginnings

In 2014, the young star V960 Monocerotis began flaring, lighting up unexpected origins for the planets coming together around it. Theoretical calculations have favored the *core accretion* scenario for planet formation: Material gloms together into a core, which then gathers gas around it. The process takes tens of millions of years. However, observations of V960 Mon instead favor *gravitational instability*, in which disk material collapses suddenly, forming gas giants in mere thousands of years. Philipp Weber (University of Santiago, Chile) and colleagues dug into the archive of the Atacama Large Millimeter/submillimeter Array (ALMA), using ALMA's longer wavelengths to probe denser areas within the spiral arms in the dust that surrounds the young star. The ALMA images show that within the spiral arms, material is already collapsing into planet-mass clumps. "No one had ever seen a real observation of gravitational instability happening at planetary scales — until now," says Weber, who published the results in the July 20th *Astrophysical Journal Letters*.

■ MONICA YOUNG

Young Warm Neptune Losing Its Air

AU Microscopii b is a Neptune-size planet that orbits its 23 million-year-old red dwarf star every 8.5 days. That's searingly close, so it's unsurprising that Hubble Space Telescope data show the planet is enveloped in a cloud of escaping gas. The surprise is that this cloud is only seen some of the time. Thanks to the planet's transits, astronomers can detect the spectroscopic signature of escaping neutral hydrogen gas; however, the first Hubble view of AU Mic b showed *no* escaping gas. Then, a year and a half later, Hubble caught a large amount of hydrogen escaping, with the gas *leading* the planet in its orbit. The contrasting observations might indicate that the star's winds and flares are shaping and altering the planetary outflow. Regardless, it is likely that this gradual, albeit highly variable loss of atmosphere will ultimately leave only a barren core behind. Keighley Rockcliffe (Dartmouth College) led the team that published the results in the August 1st *Astronomical Journal*.

■ MONICA YOUNG

 by Ken Croswell

THE DRAMA NEXT DOOR

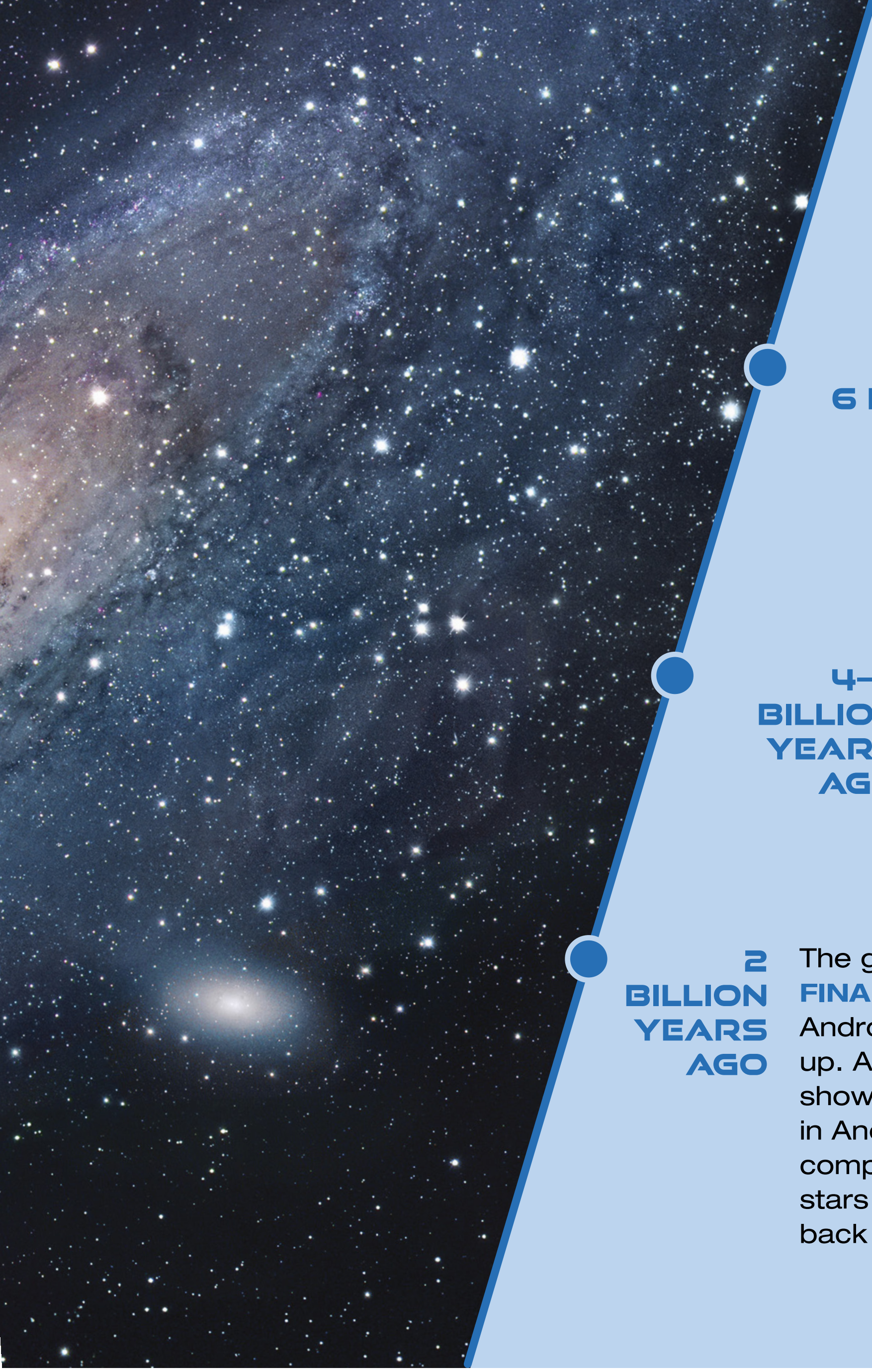
The Andromeda Galaxy is a giant spiral like the Milky Way but has had a surprisingly different — and tumultuous — past.

Stately and serene, the giant Andromeda Galaxy rules a vast empire of vassal states, such as the satellite galaxies M32 and M33. So does our own galaxy, the Milky Way. Together these two giant spirals dominate the neighborhood: Although the Local Group harbors more than 100 galaxies, most of them are satellites of one of the two superpowers. And the vast majority of the Local Group's many stars shine in either the Milky Way or Andromeda.

Astronomers have long considered these two great galaxies to be sisters. But mounting evidence indicates that the Andromeda Galaxy has led a much wilder life. Moreover, recent work suggests the Local Group once boasted another large spiral galaxy besides Andromeda and the Milky Way. This galaxy breached the frontiers of Andromeda's dark halo some 6 billion years ago, swung around its master, then plunged into Andromeda's disk 2 billion years ago. As the intruder stirred up the giant galaxy's gas and dust, it sparked new stars and supernova explosions that lit up Andromeda's entire stellar disk.

"There's a big contrast between what we have in the Milky Way and what we have in Andromeda," says Richard D'Souza (Vatican Observatory). "The Andromeda Galaxy has a very different accretion history than the Milky Way in the sense that it has accreted something much larger than the Milky Way has ever accreted during its lifetime."

Billions of stars from the intruder spiral galaxy splattered into Andromeda's stellar halo. What's more, the intruder's dense core might survive to this day as the odd elliptical galaxy M32. "It is a very strange beast, M32," says D'Souza. Its quirks, he thinks, arose from its role in the drama next door.



ANDROMEDA TIMELINE

ABOUT 6 BILLION YEARS AGO — Large spiral galaxy **FIRST BREACHES** Andromeda's sphere of influence. At this same time, observations suggest, stars stopped forming in the intruder's satellite galaxies.

4–5 BILLION YEARS AGO — Intruder galaxy **SPIRALS CLOSER**. Observations show starbirth was triggered across Andromeda's entire disk and in M32.

2 BILLION YEARS AGO — The galactic intruder **FINALLY SMASHES** into Andromeda's disk, puffing it up. Afterward, observations show, star formation decreased in Andromeda and shut off completely in M32. The youngest stars in Andromeda's halo date back to this era.

Heavenly Halos

Despite Andromeda's proximity — it's only 2.5 million light-years from Earth — astronomers were slow to recognize the recent drama. That's in part because the Andromeda Galaxy has turned out to be quite different from the Milky Way.

Surrounding the Milky Way's spiral-sculpted disk, where the Sun resides, a diffuse halo houses old stars. These halo stars possess much lower levels of iron and other metals than the Sun. Because of their great ages, halo stars have illuminated our galaxy's ancient history as well as the chemical composition of the primordial universe (*S&T:* May 2022, p. 20). Despite the stellar halo's importance, though, it constitutes a pittance of the Milky Way's total stellar mass, equivalent to roughly 1 billion Suns — just 2% of our galaxy's total stellar mass of 60 billion solar masses.

Thanks to the Gaia spacecraft, we now know that most of the Milky Way's stellar halo came from one galaxy that smashed into ours 8 to 11 billion years ago (*S&T:* Aug. 2023, p. 34). This galaxy probably had a stellar mass between that of the Large and Small Magellanic Clouds, the two brightest galaxies now orbiting the Milky Way. Because the intruder galaxy had fewer stars than a giant galaxy, and because stars make metals, it was metal-poor, which is why the Milky Way's stellar halo is metal-poor, too. From this one example, astronomers expected other spiral galaxies to have stellar halos that are also old, low in mass, and metal-poor.

But Andromeda's stellar halo doesn't look like that. In the 1980s and 1990s astronomers discovered that the galaxy's stellar halo is instead fairly metal-rich. "It was super surprising," says Eric Bell (University of Michigan) — so surprising

that some astronomers initially thought what they were seeing couldn't even be a halo.

Then, in 2001, Rodrigo Ibata (Strasbourg Astronomical Observatory, France) and his colleagues reported a stellar stream in Andromeda's southern halo. "It is a gigantic stream of stars that is absolutely unusual," says François Hammer (Paris Observatory, France), who was not involved in the discovery. "It does not exist in the Milky Way. There are streams in the Milky Way, but much, much smaller than this one."

The Giant Stellar Stream stretches across 330,000 light-years of space south of Andromeda's center — twice the distance from the Sun to the Large Magellanic Cloud. The stream's stars have iron-to-hydrogen ratios around 45% of the Sun's. That is much more metal-rich than our galaxy's stellar halo, where this ratio is typically just 1% to 10% solar.

Nor is that stream alone. "The halo of Andromeda is much, much more complex than the halo of the Milky Way," Hammer says. Andromeda's stellar halo contains 20 billion solar masses of stars, 20 times more than the Milky Way's.

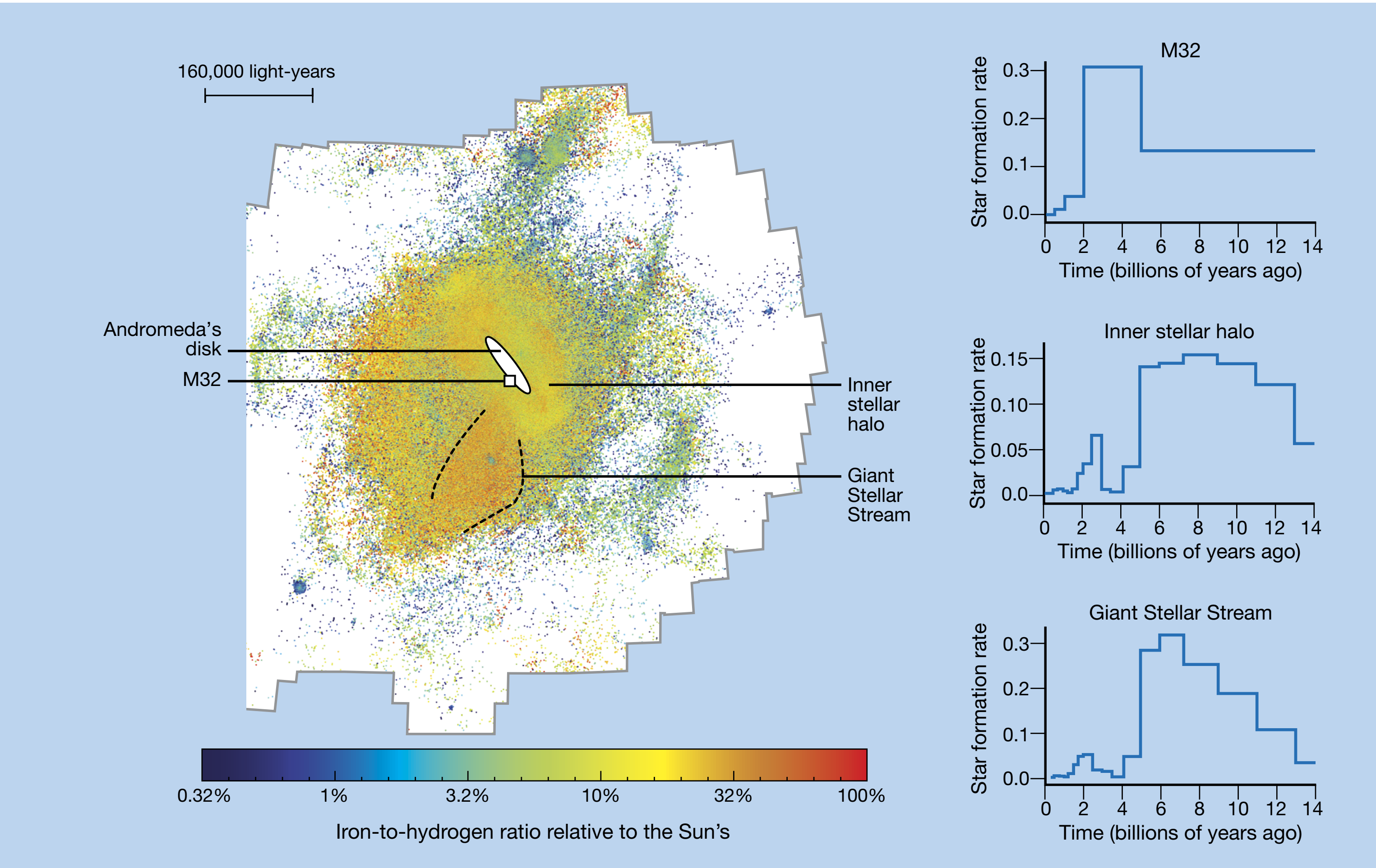
Different Disks

The following decade saw another transformative discovery, D'Souza says. It involved not Andromeda's halo but its disk. And once again, Andromeda turned out to be nothing like the Milky Way.

Most Milky Way stars, including the Sun, belong to the *thin disk*, a pancake-shape structure that measures 2,000 light-years from top to bottom in the Sun's vicinity. These stars race around the galactic center on fairly circular orbits near the galaxy's plane. Although they move fast, they start out with low velocities relative to one another, giving them what's known as a low *velocity dispersion*.

But as thin-disk stars speed through space, they encounter spiral arms and giant clouds of interstellar gas whose gravitational tugs jostle the stars up and down, left and right, forward and backward. Over the eons, the stars therefore stray more and more from their original paths around the galactic center, acquiring larger velocities relative to one another and thus larger velocity dispersions.

▼ **GOLDEN HALO** Yellow and orange dots mark stars in the Andromeda Galaxy's halo that are fairly rich in metals, as indicated by their high iron-to-hydrogen ratios. Most stars in the Milky Way's halo are so metal-poor that they'd be green or blue on the same metallicity scale. The metal-rich stars, including those in the Giant Stellar Stream, likely came from a fairly massive galaxy. The location of Andromeda's disk and the overlapping elliptical dwarf M32 are labeled but not shown. The solid gray line at top, right, and bottom outlines the limits of the Pan-Andromeda Archeological Survey.



METALLICITY MAP: RODRIGO IBATA ET AL. / *ASTROPHYSICAL JOURNAL* 2014; GRAPHS: R. D'SOUZA AND E. BELL / *NATURE ASTRONOMY* 2018 (3)

The Milky Way also has a much older stellar disk — the *thick disk* — whose stars venture about three times farther above and below the galactic plane than most thin-disk stars do. These thick-disk stars therefore have a higher velocity dispersion. In the Milky Way, however, most disk stars, such as the Sun, belong to the thin disk rather than the thick disk.

Not so in Andromeda. "The Andromeda disk is not a thin disk at all," Hammer says. "It is a thick disk."

That revelation came in 2015, when Claire Dorman, then a graduate student at the University of California, Santa Cruz, and her colleagues reported Doppler shifts of stars in Andromeda's disk, which indicate how fast the stars are moving toward and away from us. While those measurements show that the youngest stars have a fairly low velocity dispersion, they also, incredibly, reveal that stars older than just 2 billion years have a very high velocity dispersion. That means they must rise far above and below Andromeda's plane, constituting a thick disk.

In 2023, Julianne Dalcanton (Flatiron Institute) and her colleagues measured Andromeda's stellar disk to be about 5,000 light-years thick — comparable to the Milky Way's thick disk. But the youthful stars in Andromeda's thick disk indicate it must have formed much more recently, a mere 2 billion years ago.

Moreover, just as Andromeda was getting stirred up, a stellar wildfire swept through the galaxy's entire disk. "Around 2015, people were starting to notice that just about wherever Hubble looked, they would pretty much always find an overabundance of stars with ages of 2 to 4 gigayears," says Benjamin Williams (University of Washington), who led one such study. At that time, Andromeda must have been a spectacle, with brilliant young stars and supernova explosions sparkling across its disk.

The Great Galactic Intruder

In 2018 Hammer and his colleagues, and independently D'Souza and Bell, proposed a theory to explain all of Andromeda's many oddities: its massive, metal-rich stellar halo; its agitated, puffed-up stellar disk; and its recent starburst. The idea was simple. A large galaxy with perhaps 40% the stellar mass of the Milky Way looped around Andromeda and then smashed into its disk 2 billion years ago.

"The balance of evidence is really shifting toward indicating that Andromeda may have actually undergone a major merger," says Karoline Gilbert (Space Telescope Science Institute), who has studied Andromeda but was not part of either team proposing the scenario. It's surprising, she adds, because a major collision could have destroyed Andromeda's disk.

◀ COSMIC COINCIDENCE The dwarf elliptical M32 formed lots of stars 2 to 5 billion years ago, about the same time Andromeda did. This coincidence suggests that the lesser galaxy may have triggered the larger galaxy's starburst.

◀ YOUNG HALO Unlike the Milky Way, Andromeda has a halo with stars as young as just 2 billion years, around the same time its disk puffed up after a large galaxy apparently smashed into it.

◀ STREAM OF YOUTH The most dramatic feature in Andromeda's halo, the Giant Stellar Stream, spans a wide range of ages and includes stars that formed just 2 billion years ago. They likely came from the large galaxy that hit Andromeda around that same time.

DWARF ON THE OUTSKIRTS The weird elliptical dwarf galaxy M32, which appears to sit in front of Andromeda, might be the remains of a much larger galaxy that crashed into the giant spiral some 2 billion years ago.

According to the new idea, Andromeda's gravity tore stars off the large intruder — stars that wound up in Andromeda's stellar halo. That explains why Andromeda's stellar halo is so massive: The disrupted galaxy itself was big, carrying around 25 billion solar masses' worth of stars. And since larger galaxies are fairly metal-rich, that explains why Andromeda's stellar halo is, too.

The impact stirred up the stars in Andromeda's disk, making it thick. "There is no other way to reproduce this thing but by doing a recent major merger," Hammer says. Earlier simulations had successfully created the Giant Stellar Stream by invoking a collision with a much smaller galaxy, but Hammer says a small galaxy can't shake up Andromeda's disk sufficiently. The big collision also drove gas clouds together, causing them to collapse and spawn new stars across Andromeda's disk, triggering the global starburst 2 to 4 billion years ago.

Like all large galaxies, the intruder had satellite galaxies of its own, and those lesser galaxies now orbit Andromeda. These satellite galaxies share a common trait: "They stopped forming stars about 6 billion years ago, when all of them fell in and when their gas was stripped from them," Bell says. That, he says, dates the epoch when the intruder trespassed into Andromeda's sphere of influence.

Being far larger than its satellites, the intruder galaxy retained enough gas to continue forming stars up until more recently. Indeed, Andromeda's halo has stars that are just 2 billion years old, "very unlike our Milky Way," Bell says. That must be when star formation in the intruder finally got snuffed out, as it lost the last of its gas.

M32: The Survivor?

D'Souza and Bell believe the remnant of the large galaxy that hit Andromeda still exists. The original galaxy, they say, was a spiral whose arms were peeled off by Andromeda's gravity, leaving behind only a dense core: the small, compact elliptical galaxy M32.

M32 is just 24 arcminutes from Andromeda's center, closer than any of the dozens of other galaxies that orbit the large galaxy. If the two galaxies are equidistant from us, then they would be only 17,000 light-years from each other. That's just two-thirds of the distance between the Sun and the Milky Way's center.

But no one knows just how far M32 lies in front of or behind the Andromeda Galaxy, so M32's true distance from Andromeda's center is uncertain. No dust lanes from Andromeda blot out M32, which suggests that the smaller galaxy is in the foreground.

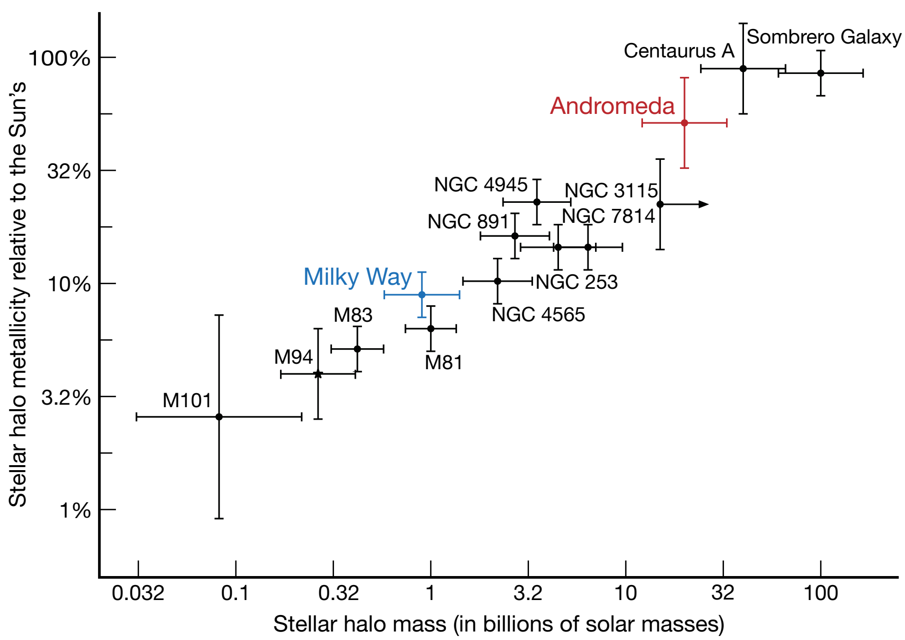
Whatever its exact location, M32 is hardly your typical elliptical, stuffed with old stars. "M32 has young stars," Bell says. "It's always been one of these very weird outliers: a young, super compact, solar-metallicity elliptical galaxy that's less massive than the Large Magellanic Cloud. It made no sense." D'Souza notes M32's strange composition: "It has a metallicity of a galaxy about 100 times larger."

It all makes perfect sense, of course, if M32 was once a much larger galaxy. Back in 1972, Sandra Faber (University of California, Santa Cruz), who first discovered M32's metal-rich nature, speculated that Andromeda had indeed torn away most of the smaller galaxy's stars.

What's more, a 2012 study found that M32 had a starburst of its own between 2 and 5 billion years ago — about the same time that Andromeda did. "It has a sharp cut-off at 2 billion years ago," D'Souza says. Thus, M32 stopped forming stars at the same time that Andromeda's disk puffed up. The 2 billion-year-old figure also marks the age of the youngest stars in Andromeda's stellar halo.

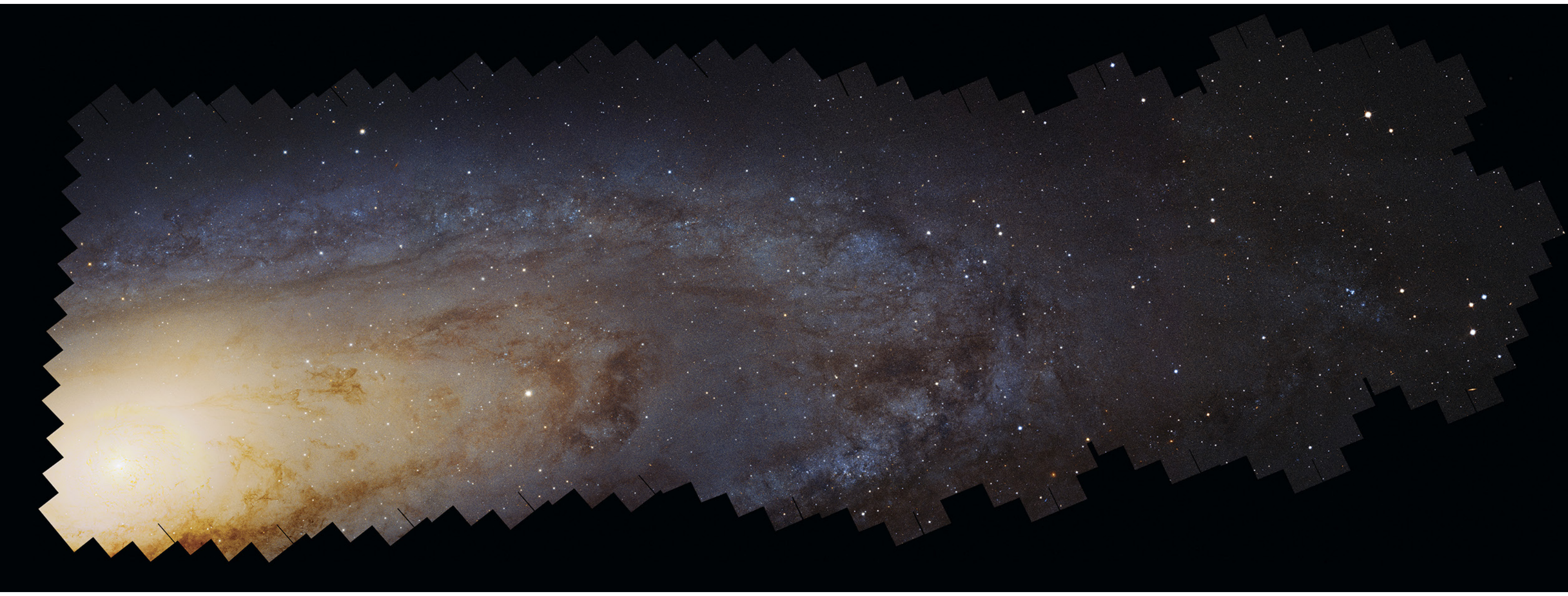
Compact elliptical galaxies such as M32 "are extremely rare," D'Souza says. The next nearest example is a small galaxy orbiting M87, the giant elliptical galaxy at the heart of the Virgo Cluster, 54 million light-years from Earth. That small galaxy, he says, likely owes its odd features to a past interaction with its huge host.

D'Souza and Bell also point at galaxies closer to home that might someday become compact ellipticals resembling



◀ **DIVERSE STELLAR HALOS** Giant galaxies sport stellar halos of widely varying masses and metallicities, depending on the sizes of the galaxies that have fallen into them. Galaxies that have accreted large amounts of material, such as Andromeda (shown in red) and the Sombrero Galaxy, have massive, metal-rich stellar halos, whereas spiral galaxies that have led quieter lives, such as the Milky Way (shown in blue) and M101, have low-mass, metal-poor stellar halos.

KATYA GOZMAN ET AL. / *ASTROPHYSICAL JOURNAL* 2023



▲ **DEEP DIVE** This panorama was taken as part of the Panchromatic Hubble Andromeda Treasury (PHAT), one of several projects that have given astronomers a close look at Andromeda's thick disk and stellar halo.

NASA / ESA / J. DALCANTON (UNIVERSITY OF WASHINGTON) / THE PHAT TEAM / R. GENDLER

M32. The first is the starburst galaxy M82, which is 12 million light-years from Earth. M82 orbits the giant spiral galaxy M81, whose gravity stirs up gas clouds in its neighbor and probably causes the intense star formation there.

More than twice as far away, at a distance of 28 million light-years, the Whirlpool Galaxy (M51) sports spectacular spiral arms whipped up by a satellite galaxy at the edge of the great galaxy's stellar disk. The Whirlpool's gravity is tearing stars off, converting its companion into what D'Souza and Bell say will also one day be a compact, M32-like elliptical.

However, not all astronomers are convinced that M32 was the culprit behind the recent drama in Andromeda. "M32 is very special," Hammer acknowledges. But he thinks the Andromeda Galaxy obliterated the intruder. "It has been completely destroyed."

As Hammer explains, such a massive satellite galaxy suffers a drag force that moons orbiting planets do not experience: *dynamical friction*. A massive satellite revolving around a giant galaxy speeds through the dark matter in the giant's dark halo. Never mind that no one yet knows what dark matter is; it both feels and exerts gravitational force. Thus, as the satellite moves through the dark-matter particles, they lurch toward the satellite. But by the time the particles reach where the satellite was, it has moved on, so the dark-matter particles bunch up behind the satellite. The gravitational pull of this bunch tries to yank the satellite backward, slowing it down and causing it to plummet into the larger galaxy.

The more massive the satellite galaxy, the faster it spirals in and meets its maker — and its master. That's why the Milky Way's two most massive satellite galaxies, the Magellanic Clouds, will eventually merge with the Milky Way.

Andromeda's big satellite galaxy faced ferocious dynamical friction, because the satellite had about 10 times as many stars as the Large Magellanic Cloud. Thus, Hammer says, the intruder quickly plunged into the Andromeda Galaxy and ceased to exist. For that reason, M32 can't be the intruder galaxy's remnant.

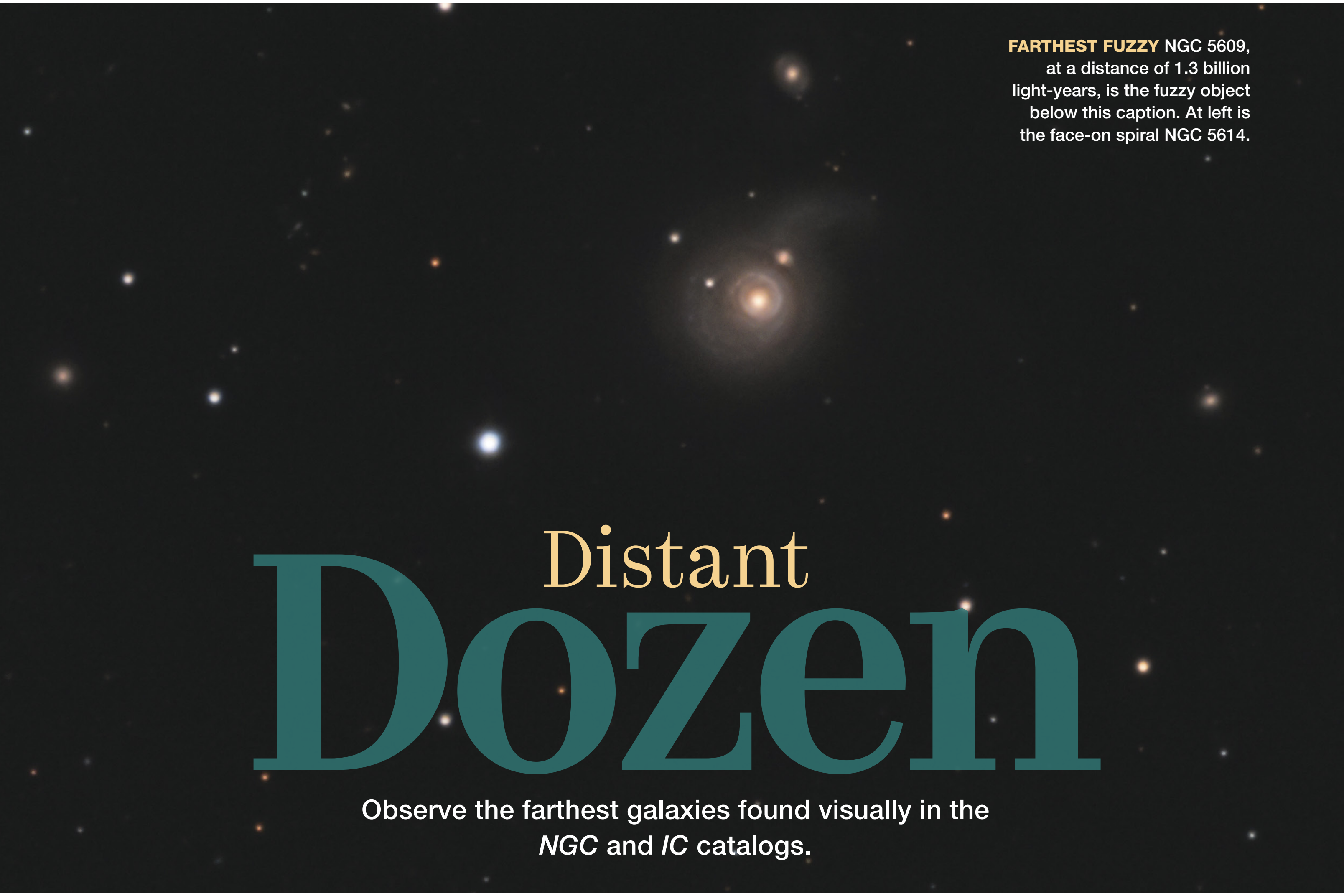
Still, M32 did have a starburst at the same time that Andromeda did. And M32's metal-rich nature does suggest it was once a much larger galaxy.

Gilbert calls this evidence for M32's interference in Andromeda circumstantial. "But it's an intriguing circumstantial," she admits. Nevertheless, the M32 idea faces a problem. The small galaxy may be in the wrong place to have been the guilty party: It's south of Andromeda's disk, whereas simulations suggest any surviving remnant of the intruder should be east of Andromeda in order to produce its Giant Stellar Stream.

"I think we will have the answer within a few years," Hammer says, "because the proper motion will tell us the truth." A measurement of M32's proper motion — its apparent sideways movement on the sky — will come from the Hubble Space Telescope and Gaia spacecraft, showing whether the odd galaxy was in the right place at the right time to stage the drama in Andromeda.

Whatever the verdict is for M32, Andromeda's life story seems to be nothing like the Milky Way's, which has been quiet for the past 8 billion years. "You learn as a student that M31 is sort of like a Milky Way twin," Williams says. "But you study it in detail and realize it has a lot of pretty significant differences with the Milky Way."

■ **KEN CROSWELL** is the author of a book about our galaxy, *The Alchemy of the Heavens: Searching for Meaning in the Milky Way*. His feature article on the Milky Way's life story appeared in the August 2023 issue.



FARTHEST FUZZY NGC 5609, at a distance of 1.3 billion light-years, is the fuzzy object below this caption. At left is the face-on spiral NGC 5614.

Distant Dozen

Observe the farthest galaxies found visually in the *NGC* and *IC* catalogs.

I've always been a big fan of chasing distant light. Nothing excites me more than glimpsing a remote galaxy whose light has been traveling for more than a billion years. I'm constantly amazed by the long journey of the ancient photons that I've captured at the eyepiece when I'm out under the dark skies of my high-desert home in West Texas.

My research into the most distant galaxies in the *New General Catalogue of Nebulae and Clusters of Stars* (*NGC*) and *Index Catalogue* (*IC*) began in my living room several years ago. *Sky & Telescope* Contributing Editor Steve Gottlieb was visiting for an observing run, but a rare foggy night shut down our plans. Instead, we had a lively discussion about the farthest galaxies in the *NGC* and *IC*. Little did I know that our conversation would lead to a deep dive into the scientific literature and the discovery history of these galaxies. We had much help on this journey from Wolfgang Steinicke and Akarsh Simha.

When we examined the published redshifts, we found 94 galaxies with a light-travel time of *at least* a billion years. It surprised me that so many galaxies were beyond this threshold! It was German astrophotography pioneer Max Wolf who identified 66 of our sample galaxies on his early photographic plates. In fact, Wolf discovered the four most remote ones — but that's another story. The nature and distances of such mysterious "nebulae" were completely unknown at the time of their discovery in the late 19th and early 20th centuries. Now, a little more than a century later, astronomers have made significant advances in gauging the distance scale of the universe using a variety of standard candles (see, e.g., *S&T:* Oct. 2022, p. 12). What a fantastic era for amateurs today, that we have access to all this knowledge and these resources!

Wolf's Story

Max Wolf found 1,123 new objects listed in the *Index Catalogue* with the 16-inch Bruce astrograph at the Heidelberg Observatory in Germany. Of these, 66 have light-travel times of 1 billion years or more, including the four most distant galaxies: IC 4017 (2.21 billion light-years); IC 2657 (2.10); IC 3389 (1.63); and IC 2677 (1.51).

GARY IMM

As a dedicated visual observer, I was interested in these distant galaxies — I established which were the 12 farthest found by these observing pioneers and proceeded to observe them. Let's tour these Distant Dozen — eight are targets in the spring sky and four in the autumn sky. We'll start with the galaxy with the highest redshift and work our way in. Throughout my research on the 94 "far out" galaxies, I've relied on the NASA Extragalactic Database (NED) and Wolfgang Steinicke's revised *NGC/IC* catalog (**https://is.gd/steinicke_ngcic**) as the primary references for identification and data. Unless stated otherwise, I observed these objects with my 48-inch f/4.0 reflector.

The Strange Case of NGC 1262

If you google "most distant object in the *NGC*" one hit will be **NGC 1262**, a low-surface-brightness, barred spiral galaxy in Eridanus. American astronomer Francis Leavenworth discovered it with the 26-inch Clark refractor at the University of Virginia on November 12, 1885. Its claim to fame is a reported redshift of $z = 0.116$, implying a light-travel time of 1.5 billion years.

NGC 1262 light-travel time: **686 million years**

The light of NGC 1262 spreads out over nearly 1′, which translates to a physical diameter of more than 400,000 light-years at that distance, making it a gargantuan spiral. (For comparison, the Milky Way is 100,000 light-years across.) But Steve and I often discussed our doubts about NGC 1262's redshift. In addition to its unusually large diameter, the photographic detail on an image taken by PanSTARRS (one of two 1.8-meter telescopes atop Haleakalā on the island of Maui) suggested it was much closer. I've viewed hundreds of galaxies at a billion light-years, and most appear in the eyepiece (and on sky survey images) as just small, faint fuzzies. So, I devised a plan to address our doubts: Request time on a professional telescope to pin down the redshift of NGC 1262.

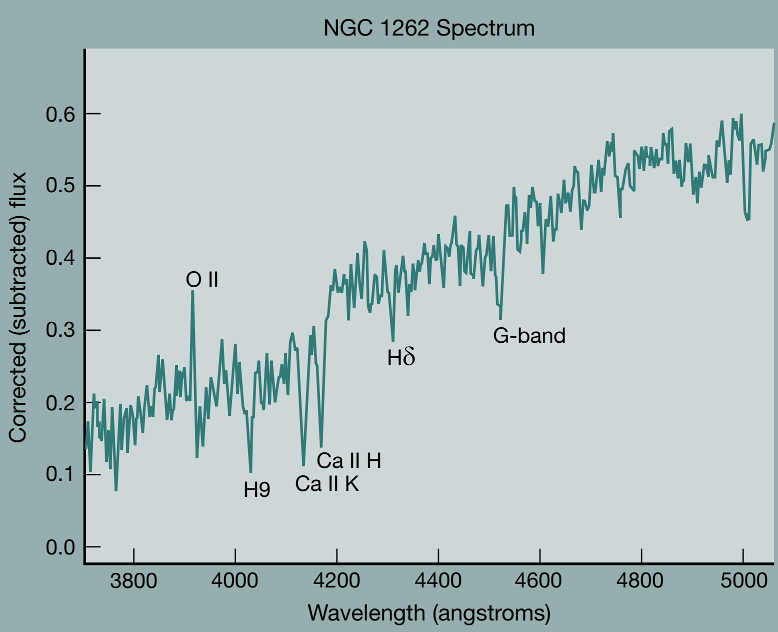
Telescope Time

I talked to my friend Stephen Odewahn, a resident astronomer at McDonald Observatory in West Texas (see *S&T:* Feb. 2021, p. 36), about measuring the redshift of NGC 1262 to solve this mystery. He said he'd happily assist me with the project — we needed to secure observing time on the 107-inch Harlan J. Smith Telescope using the Virus-P spectrograph. This is the prototype of the fiber-fed spectrographs for the Dark Energy Experiment conducted using the Hobby-Eberly Telescope (the 11-meter telescope at the McDonald site). Yes! I now had help from a professional astronomer.

The next step was applying in person with the head of the telescope-time allocation committee, Anita Cochran. She supported the project but warned me the spectrograph was only available during two periods that would coincide with when NGC 1262 was well-placed in the sky. She contacted the astronomers who had been allocated telescope time then (through competitive proposal submissions). Both teams agreed to collect the data for me during their runs. Excellent news! Now we just needed a clear night.

First on the schedule in late August were Midge Hartshorn and Jason Young of Mt. Holyoke College (Massachusetts). Unfortunately, it rained nearly every day and was mostly cloudy at night, and when it was clear the telescope experienced mechanical problems. Their run was a total washout. Now I had only one more chance to collect the data.

Next up, in November, was Ann Isaacs of the University of Minnesota. We had our fingers crossed that her run would



Feature	Rest Wavelength	Observed Wavelength
O II	3727.000	3915.220
Ca II K	3934.000	4134.272
Ca II H	3968.000	4168.430
H9	3835.390	4027.730
Hδ	4101.740	4309.955
G-Band	4305.000	4523.596

◀ **WRITTEN IN THE LINES** This spectrum of NGC 1262 dislodged the galaxy as the most distant object in either the *NGC* or the *IC* that can be visually observed. Until the author's requested observations, sources placed NGC 1262 at a distance of 1.5 billion light-years. These data placed it much closer, at almost 700 million light-years.

JIMI LOWREY / STEPHEN ODEWAHN / MCDONALD OBSERVATORY / ANN ISAACS (UNIVERSITY OF MINNESOTA)

be successful. Ann emailed to let me know that fortunately things went smoothly, and she'd collected the data on NGC 1262. What an enormous relief!

It was now up to Stephen Odewahn to work his magic. His next step was to reduce the spectroscopic data and measure the redshift. With much anticipation, I waited for Stephen's results. I was excited when I received his email saying he had identified six lines in the spectrum. The data showed NGC 1262 had a radial velocity of 15,169 km/s, corresponding to a redshift of $z = 0.0506$. Assuming a Hubble constant (H_0) of 69.6, its light-travel time is only 686 million years. It looks like Steve's and my hunch was correct — NGC 1262 is nowhere near the most distant NGC galaxy.

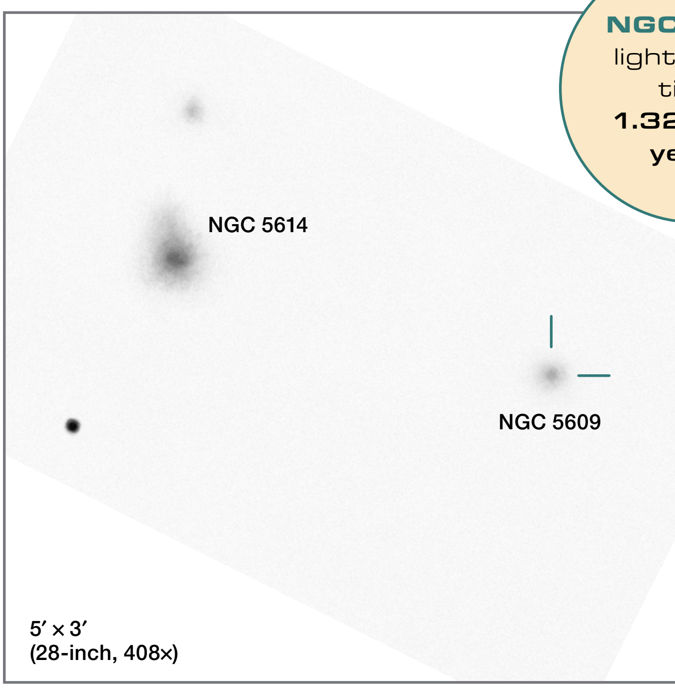
The Champion

With NGC 1262 knocked off its perch, the most distant visually discovered galaxy on our list is now 15.6-magnitude **NGC 5609** with a light-travel time of 1.32 billion years. Irish engineer Bindon Blood Stoney uncovered this remote galaxy on March 1, 1851. Between 1850 and 1852, Stoney was observing assistant to William Parsons, the Third Earl of Rosse. Using the Earl's 72-inch Leviathan, he discovered 105 *NGC* objects and eight that appeared in the *IC*.

Stoney was examining NGC 5614 for possible spiral structure or resolution into stars when he found three faint nebulae nearby: NGC 5609, NGC 5613, and NGC 5615. He sketched the field and placed the new objects correctly around NGC 5614, but he had no clue the pale light from NGC 5609 had traveled for more than a billion years!

This fascinating quartet is located 3.8° south-southwest of 3.0-magnitude Gamma (γ) Boötes. I've observed NGC 5609 many times over the years, and in an 18-inch reflector it appears as a tiny, circular spot (visible with direct vision) with a brighter center. NGC 5614 (also known as Arp 178) sports a tidal plume from a past interaction with a neighbor.

▼ **THE FIELD OF NGC 5609** The current record-holder for the most distant, visually observed galaxy is NGC 5609, which lies at a distance of 1.32 billion light-years. Spend some time with nearby NGC 5614, a face-on spiral at a distance of "merely" 180 million light-years. You can catch these targets in the morning hours later in winter; otherwise, you'll have to wait for spring to snag them in the evenings. Aperture and magnification used for the sketches are noted.



NGC 5609
light-travel time:
1.32 billion years

The Runner-Up

IC 2221 is the second most distant visual discovery in the *NGC/IC* catalogs with a light-travel time of 1.18 billion years. French astronomer Stéphane Javelle spotted it on the night of February 28, 1900, using the 30-inch refractor at Nice Observatory in southern France.

Although Javelle is little known today, his contributions to the *IC* are incredible. He discovered 1,460 faint nebulae between 1891 and 1903 using the large refractor. These finds make him the third most prolific contributor to the entire *NGC/IC* catalogs after William and John Herschel. Javelle continued to explore the skies until 1911, adding another 400 discoveries that were never published.

IC 2221 lies in a desolate region in Lynx, 8.3° northeast of 1.6-magnitude Castor, or Alpha (α) Geminorum. I easily saw the 15.2-magnitude galaxy with direct vision at 488× in my 48-inch and noticed a bright starlike nucleus. IC 2222, a more prominent foreground galaxy, is only 2′ northeast. Although Javelle's original position was accurate, some references incorrectly list a completely different object here (PGC 22713).

The Mighty Lion

The famous comet hunter Lewis Swift discovered the 15.2-magnitude elliptical galaxy **IC 685** on April 11, 1888, with his 16-inch Clark refractor. Swift was searching for new nebulae within the Lion's hindquarters, formed by the three 2nd- and 3rd-magnitude stars Beta (β) Leonis, or Denebola, Delta (δ) Leonis, and Theta (θ) Leonis. IC 685 lies 1.3° to the east-southeast of the 10th- and 11th-magnitude galaxies NGC 3607 and NGC 3608, which are fine targets for a small telescope.

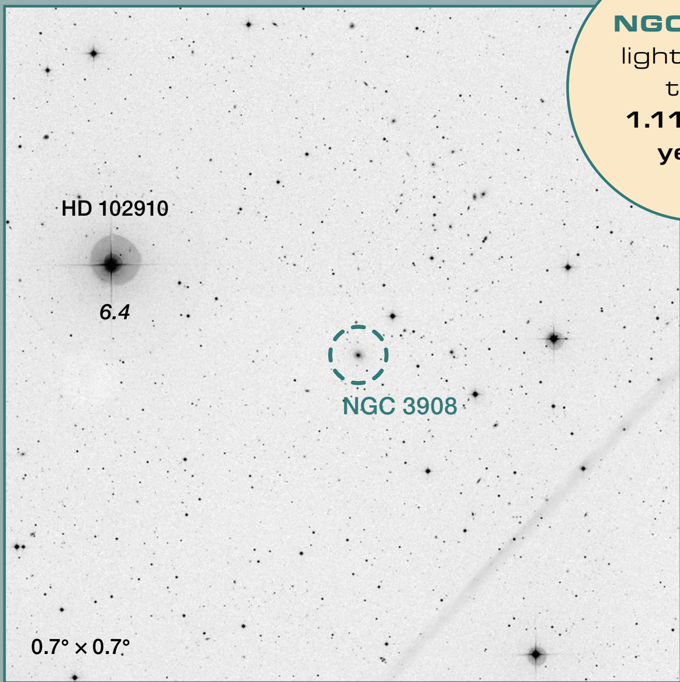
Leo's distant denizen has a light-travel time of 1.14 billion years. At 613×, I saw it using direct vision as a slightly extended glow with a condensed nucleus.

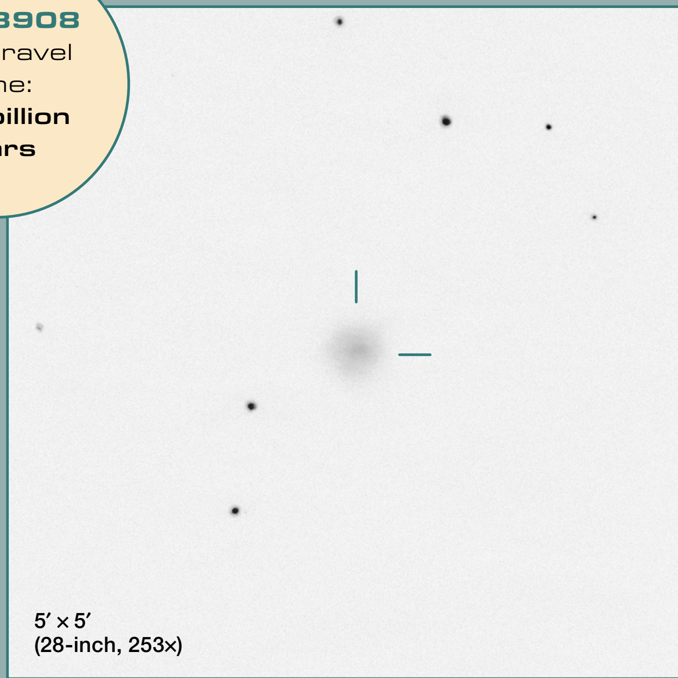
Swift is notorious for positional errors when reporting new nebulae, and IC 685 is no exception. His published coordinates and description leave room for doubt, and some sources propose an alternate galaxy for IC 685. Both my sources (NED and Steinicke) list this galaxy as Swift's IC 685.

NGC 3908 is another of Swift's finds in Leo, and this one has a light-travel time of 1.11 billion years. He swept up the 15th-magnitude elliptical on April 10, 1885, but his reported position is 7′ south of PGC 36967, the galaxy usually identified as NGC 3908.

ALL SKETCHES BY HOWARD BANICH

NGC 3908
light-travel time:
1.11 billion years

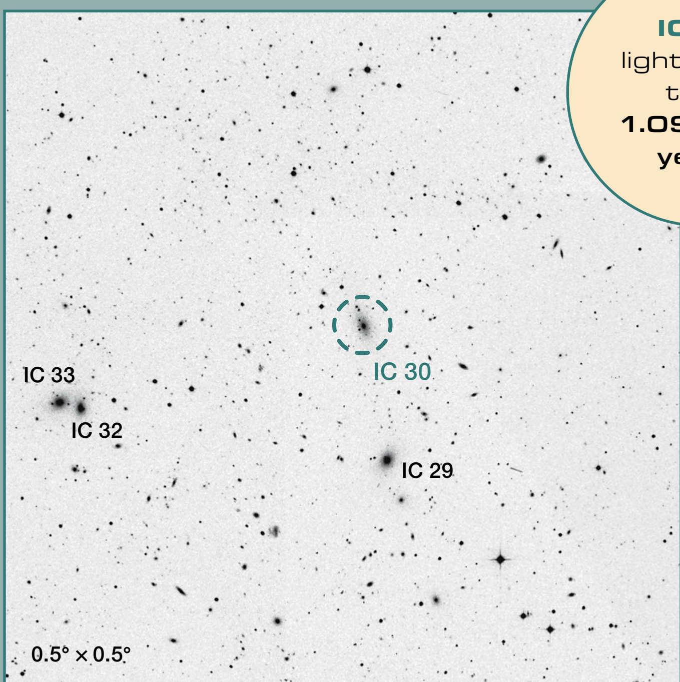




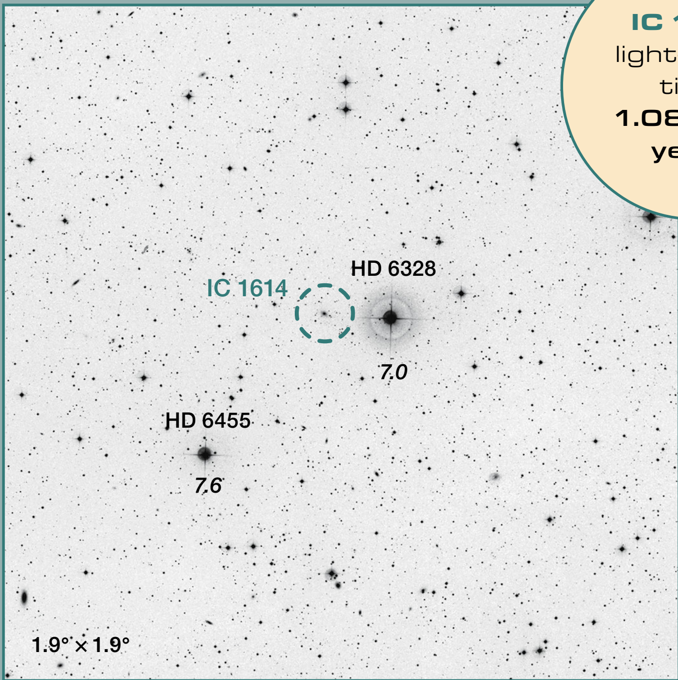
▲ **LEONINE DELIGHTS** Spring nights usher in Leo, the Lion. Pop into the constellation to look for IC 685 and NGC 3908, the latter of which is pictured here. To get to NGC 3908, look for 2.1-magnitude Denebola and from there slew 2.4° nearly due south (use HD 102910 to guide you).

▼ **LARGER THAN RECORDED?** Images of IC 30 hint at a halo larger than the galaxy's normally reported size. This lenticular lies in a rather sparse area of sky in Cetus, the Sea Monster. To reach the galaxy, you can star-hop on these winter nights some 5½° northeast from 3.6-magnitude Iota (ι) Ceti to 5.7-magnitude 12 Ceti and from there continue the line a smidgen more than 2° on to IC 30.

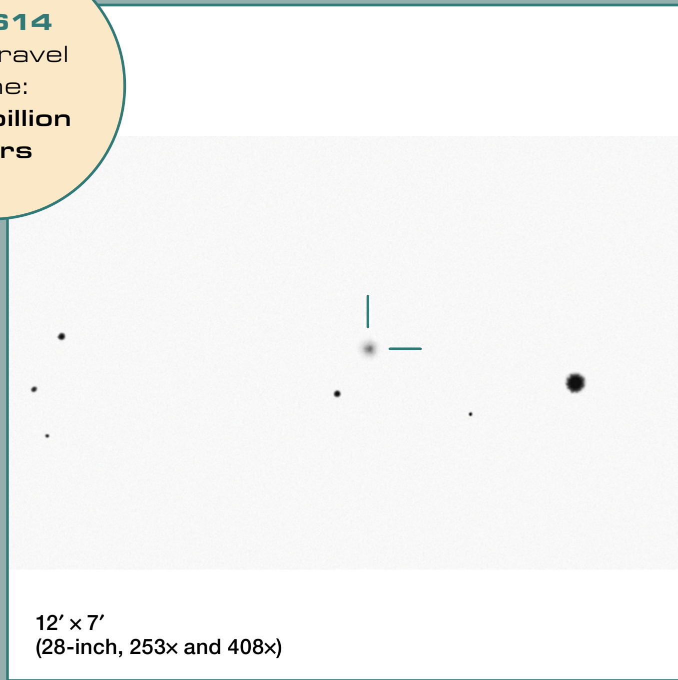
IC 30
light-travel time:
1.09 billion years



DSS IMAGES: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

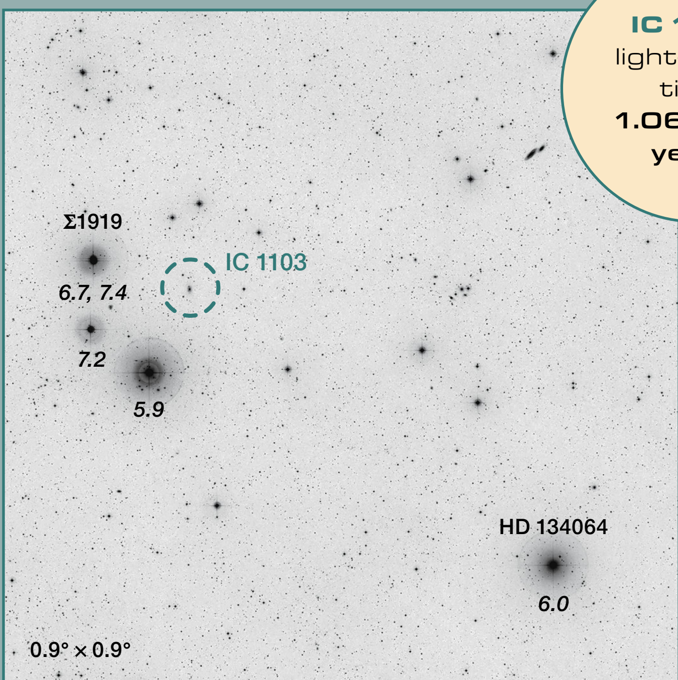


IC 1614 light-travel time: **1.08 billion years**

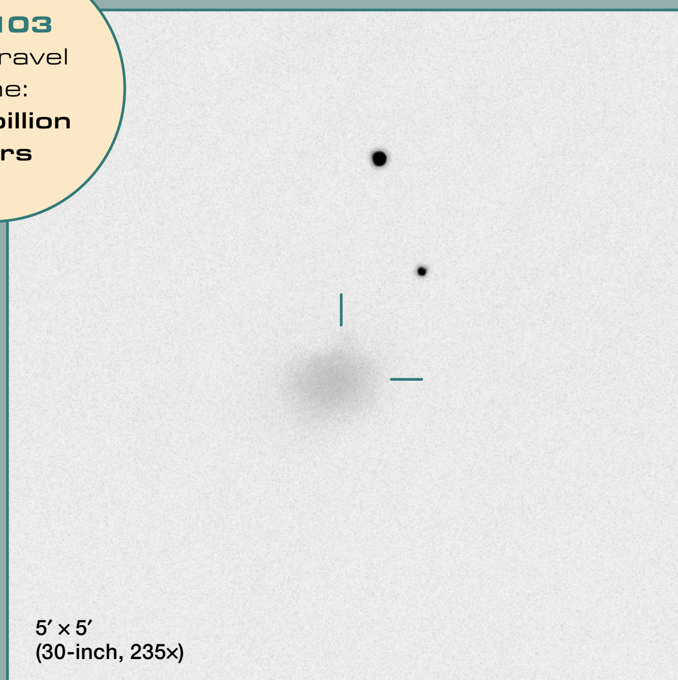


▲ **IN THE NORTHERN FISHES** Head to northernmost Pisces to spot IC 1614, an elliptical galaxy. The 7th-magnitude star HD 6328 provides a handy jumping-off point to guide you to your target. Look for the galaxy 6′ almost due east of the yellowish-orangish star.

▼ **YET ANOTHER JAVELLE DISCOVERY** IC 1103 is an elliptical galaxy that you'll find in Serpens. Three 6th- and 7th-magnitude stars on the constellation's northwestern border with Boötes (the double Σ1919, HD 134943, and HD 135080) arranged in an arc point the way to IC 1103.



IC 1103 light-travel time: **1.06 billion years**



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Astronomers have suggested that NGC 3908 is too dim for Swift to have seen with a 16-inch telescope. But I know of two observations made by amateurs using a similar aperture: one with a 15-inch reflector by Amelia Goldberg and another with a 16-inch reflector by Chuck Dethloff. After hearing these observers' confirmations, I feel confident the eagle-eyed Swift indeed found NGC 3908.

Locate this galaxy by dropping 2.4° south from Denebola to 6.4-magnitude HD 102910. Then scan 16′ farther southwest. I picked up NGC 3908 with direct vision at 488× as a small, round patch with a bright, starlike nucleus and a pale halo.

A Whale of a Time

Javelle discovered **IC 30** on November 6, 1891, in the northwestern corner of Cetus, the Sea Monster, 2° northeast of 5.7-magnitude 12 Ceti. This lenticular has a light-travel time of 1.09 billion years. The galaxy spans 0.7′, implying a diameter of 200,000 light-years, but deep images show a diffuse halo extending twice this size! My brief notes describe 15.1-magnitude IC 30 as a "small, fairly faint glow, with a conspicuous nucleus and a weak halo." Javelle also discovered 14th-magnitude IC 29 just 6′ south and the close pair IC 32 and IC 33 (both 15th magnitude) about 13′ east-southeast of IC 30.

We need to make a small detour into Pisces to get to the next galaxy on my list. Javelle spotted 15.2-magnitude **IC 1614** on November 30, 1899. At a distance of 1.08 billion light-years, it's situated only 6′ east of the 7th-magnitude yellow-orange star HD 6328. I noted a moderately faint, round spot with a tiny halo.

IC 1757 is my favorite galaxy on this list because it's only 1.5′ from the foreground edge-on galaxy IC 1756. I'm a big fan of super-thin galaxies, and there's nothing more appealing than a twofer. Famed visual observer Edward Emerson Barnard found both objects while at Lick Observatory. He was probably observing with the 36-inch Clark refractor but never published the discovery date. At magnitude 15.7, IC 1757 has a light-travel time of 1.07 billion years, while its neighbor IC 1756 is more than three times closer.

This pair is 3.5° south-southwest of the close double Alpha (α) Piscium (magnitudes 4.1 and 5.2 at 1.8″ separation). My notes say, "Wow! Now we're talking! An edge-on and a billion-year light-travel galaxy are in the same 9′ field of view. I can easily see IC 1757 as a small, round spot with a brighter core."

A Monster in Serpens

Javelle discovered **IC 1103** in Serpens on July 20, 1892. Do you see a pattern here? Javelle was the first to see five members of the Distant Dozen! This 14.4-magnitude elliptical lies 1.06 billion light-years away but is

IC 1757
light-travel time:
1.07 billion years

48-INCH BEHEMOTH The author designed his telescope so as to explore exotic objects and distant stellar outposts (such as IC 1757) from his mountainside observatory. His friend Larry Mitchell is perched atop a tall ladder.

TELESCOPE AND LADDER: JIMI LOWREY; DSS IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

intrinsically ultra-bright — one of the 1,525 most optically luminous galaxies out to a redshift of $z = 0.3$ (more than 3 billion light-years).

A convenient way to locate IC 1103 is to first identify the stellar pair Σ1919, two 7th-magnitude stars separated by 23″. IC 1103 is just 17′ to the double's west-southwest. Using 542×, I logged the galaxy as "small, round, and faint, with a bright nucleus and a round halo." As a bonus, I picked up the nearby galaxy LEDA 1583483, only 1.6′ to the southeast — the 16.8-magnitude galaxy was small and even in brightness.

Deep into Virgo

IC 1101 is a supergiant elliptical galaxy — the brightest member of the rich cluster Abell 2029. Edward Swift, Lewis Swift's son, found this galaxy when he was 19 years old on June 19, 1890, while observing with his father's 16-inch refractor. But as they continued with their observations that night and moved the telescope to a new field, Lewis and Edward later couldn't agree on the appearance of their target. As a result, their description is missing in the *IC*.

IC 1101 is one of the largest known galaxies, having grown through mergers with nearby cluster members. With a magnitude of 13.7 and a light-travel time of 1.04 billion years, it's the most accessible galaxy on our list for amateurs to observe and in so doing join the "billion-light-year club" (see *S&T:* May 2019, p. 57). IC 1101 lies 4° north-northwest of the showpiece globular cluster M5, and from a dark site it's within range of 10-inch to 12-inch telescopes. At 375×, I recorded a small oval with direct vision in a busy starfield.

Javelle snagged **IC 886**, his last faraway target on our list, on June 10, 1893. Of the 15.3-magnitude elliptical, which lies at a distance of 1.02 billion light-years, he recorded, "very faint and small with a poor definition, envelops a brighter point." A handy marker is 6.8-magnitude HD 116545 located 9′ northeast of the galaxy. In my brief notes using 488× I describe IC 886 as "small and round, with a starlike nucleus and a faint outer halo."

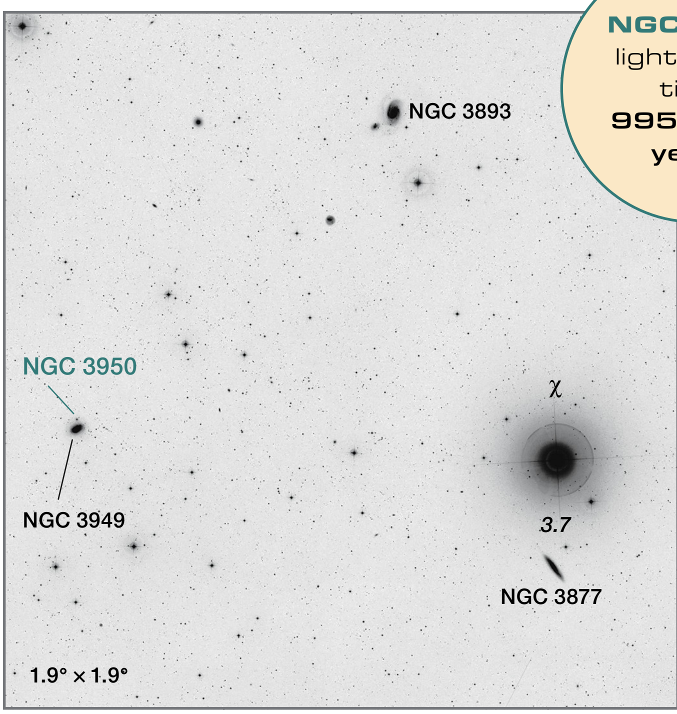
We'll briefly pop into Ursa Major for our next target. **NGC 3950** is my second most favorite galaxy in this list — another two-for-the-price-of-one special as it lies just 1.5′ north of the beautiful 11.1-magnitude spiral NGC 3949. William Parsons's son Lawrence, the Fourth Earl of Rosse, discovered this far-flung galaxy on April 27, 1875. NGC 3949 lies a "mere" 55 million light-years away, while NGC 3950 is a staggering 940 million light-years behind it!

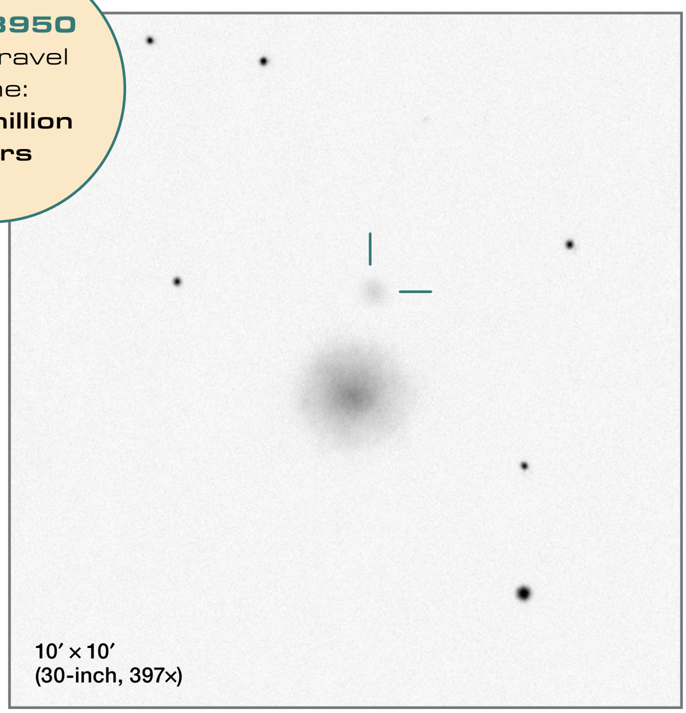
This mismatched duo is located 1.3° east-northeast of 3.7-magnitude Chi (χ) Ursae Majoris. At 542×, I saw it as small and relatively faint with a smooth surface brightness.

French astronomer Édouard Stephan, discoverer of the famous Stephan's Quintet, found **NGC 5285** on April 29, 1881. Stephan used a 31-inch silver-on-glass reflector designed by Léon Foucault, a significant advance over the speculum-mirror scopes of the day.

NGC 5285 is a 14.2-magnitude giant elliptical in Virgo (tied for second brightest with NGC 1262 on our tour) with a light-travel time of 960 million years. It's the dominant galaxy in a faint cluster. Observing at 488×, I picked up the galaxy with direct vision as a small, barely oval glow.

NGC 3950
light-travel time:
995 million years





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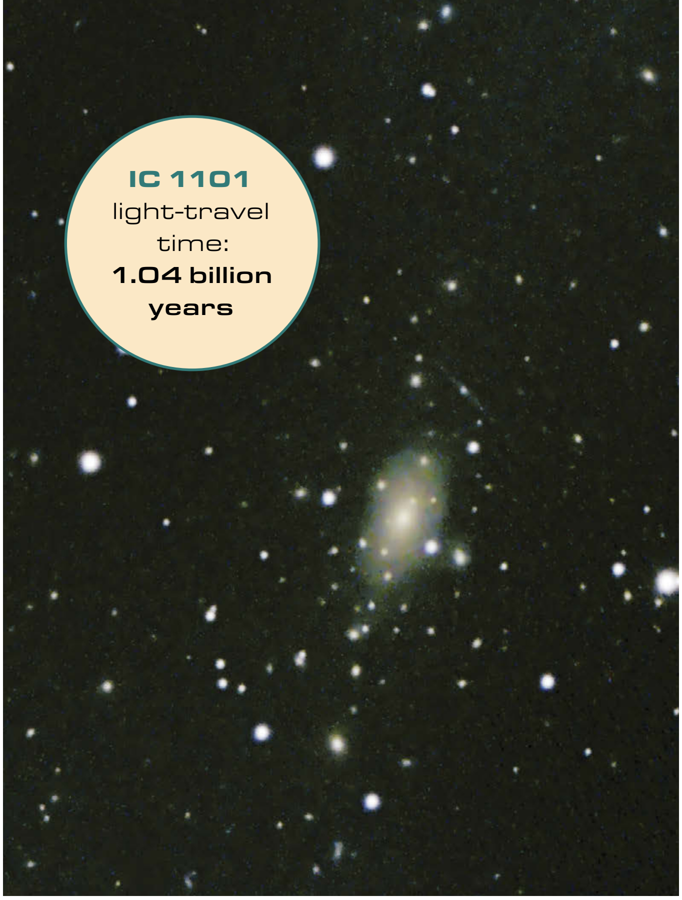
▲ **NOT AS FAR** The elliptical galaxy NGC 3950 is one of the closer targets on the Distant Dozen list and lies at a "mere" 995 million light-years away in Ursa Major. You'll find it right next to NGC 3949, some 1.3° east-northeast of 3.7-magnitude Chi Ursae Majoris.



▲ **SUPERGIANT ELLIPTICAL** IC 1101, at a light-travel time of 1.04 billion years in Virgo, is one of the largest galaxies known, spanning nearly 400,000 light-years. If you've just visited IC 1103, drop down a bit less than 13½° along the western border of Serpens and slide over into Virgo. IC 1101 lies less than 1° east-northeast of 6.2-magnitude HD 134047.

So that's the Distant Dozen — the 12 most distant galaxies found by visual observers in the *NGC/IC* catalogs. For a deeper dive, you can download a copy of my "Far-Out Galaxy List," which includes all 94 galaxies with a light-travel time of 1 billion years or more at **https://is.gd/DSF_ObservingLists**.

It's been a long road since my conversation with Steve on that foggy night several years ago in my living room. I've spent many hours observing these Distant Dozen galaxies and researching their historical and technical data. It's been quite an adventure. When I'm out under a dark sky viewing a faraway galaxy, I often try to wrap my mind around the mind-boggling distances of the universe. I'm reminded of what Dorothy told her little dog in *The Wizard of Oz*: "Toto, I've a feeling we're not in Kansas anymore!"

■ **JIMI LOWREY** has been chasing faint, distant galaxies since the early 1970s. The more obscure and unusual the object, the better! He looks forward to your comments and questions at **jimilowrey@gmail.com**.

NOTES OF APPRECIATION
It is humbling for me as an amateur to get professional telescope time at McDonald Observatory and to make a scientific contribution with the corrected redshift for NGC 1262. I want to thank Ann Isaacs who shared her most-valuable telescope time and collected the data. I would also be lost without the help and guidance of my friend and professional astronomer Stephen Odewahn, who reduced the data and measured the new redshift for NGC 1262.

Distant Dozen (Plus an Imposter)

Object	Constellation	Type	Mag(v)	Size	Distance (G l-y)	RA	Dec.
NGC 1262	Eridanus	Barred spiral	14.2	0.9′ × 0.7′	0.686	$03^h\ 15.6^m$	–15° 53′
NGC 5609	Boötes	Spiral	15.6	0.4′ × 0.3′	1.32	$14^h\ 23.8^m$	+34° 51′
IC 2221	Lynx	Elliptical	15.2	0.2′	1.18	$08^h\ 05.1^m$	+37° 27′
IC 685	Leo	Elliptical	15.2	0.4′ × 0.3′	1.14	$11^h\ 22.1^m$	+17° 45′
NGC 3908	Leo	Elliptical	15.0	0.4′	1.11	$11^h\ 49.9^m$	+12° 11′
IC 30	Cetus	Lenticular	15.1	0.7′ × 0.4′	1.09	$00^h\ 34.2^m$	–02° 05′
IC 1614	Pisces	Elliptical	15.2	0.3′	1.08	$01^h\ 05.1^m$	+33° 11′
IC 1757	Cetus	Peculiar	15.7	0.6′ × 0.2′	1.07	$01^h\ 57.2^m$	–00° 28′
IC 1103	Serpens	Elliptical	14.4	0.5′ × 0.3′	1.06	$15^h\ 11.6^m$	+19° 12′
IC 1101	Virgo	Elliptical	13.7	1.2′ × 0.6′	1.04	$15^h\ 10.9^m$	+05° 45′
IC 886	Virgo	Elliptical	15.3	0.3′	1.02	$13^h\ 24.0^m$	–04° 24′
NGC 3950	Ursa Major	Elliptical	15.7	0.3′	0.995	$11^h\ 53.7^m$	+47° 53′
NGC 5285	Virgo	Elliptical	14.2	0.8′	0.960	$13^h\ 44.4^m$	+02° 07′

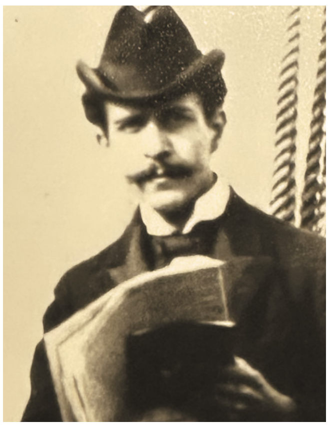
Angular sizes are from recent catalogs. Light-travel times calculated using H_0=69.6. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

YANNICK JUILLET

E. M. Antoniadi
The Astronomer Who Decoded Mars

This Greek-French astronomer is perhaps history's greatest visual planetary observer.

Eugène Michel Antoniadi is one of the most famous of all planetary astronomers. Known for his artistic, highly detailed, and accurate drawings of Mars, he's also remembered for his battle with Percival Lowell over the so-called Martian canals. However, despite his fame, Antoniadi's life story is relatively little known. How did this man from the remote capital of the dying Ottoman Empire become such a skilled observer and rise in prominence to challenge the authority of one of the era's most celebrated astronomers?



Coming of Age in Tatavla

E. M. Antoniadi was born on March 1, 1870, in the Tatavla quarter of Constantinople (present-day Istanbul, Türkiye). His parents were wealthy merchants, and growing up, Antoniadi wanted for little.

Astronomy during the Ottoman period had reached its heyday centuries earlier when, in 1421, the Timurid sultan Ulugh Beg established the great observatory at Samarkand in present-day Uzbekistan. However, scientific progress slowed badly in the centuries that followed — so much so that the Copernican theory was not officially recognized in the Ottoman Empire until early in the 19th century. Thankfully, there was an accumulated legacy of astronomical literature available in Greek, French, and English, which Antoniadi, who was fluent in all three languages, must have devoured.

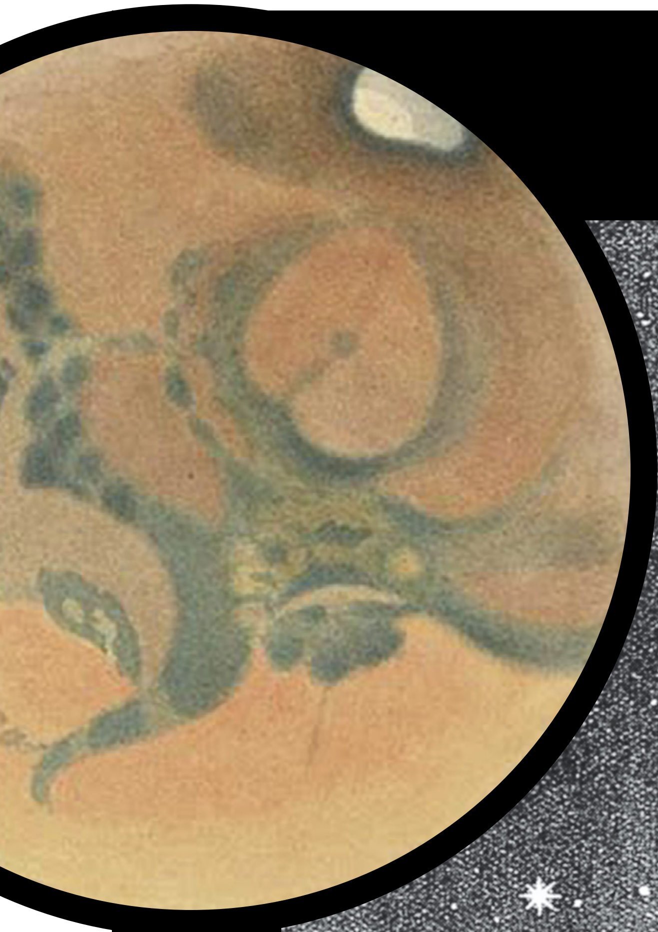
In addition to receiving an excellent education, Antoniadi seems to have been something of a savant, with exceptional powers of concentration and a compulsion to focus obsessively on whatever captivated him, even at the exclusion of pursuits he embraced with passionate intensity at other times. He was interested in how things work and in extracting the underlying rules that govern the behavior of systems, whether in astronomy or works of architecture. In people, not so much. In addition, he seems to have had a nearly photographic memory, which enabled him to render a landscape from memory after seeing it once — something that would later stand him in good stead when he began to draw Mars.

Antoniadi's tendency to withdraw into intense but solitary interests was enhanced by the distressing social and political circumstances of his youth. By the mid-19th century, the Ottoman Empire was already being referred to as "the sick man of Europe" as it charted an inevitable path through despotism to terminal decline and finally extinction. A significant catalyst was the Russo-Turkish War of 1877–78, leaving the Empire with huge reparations to pay the victors, which wreaked havoc with its finances. Although Antoniadi was relatively unaffected in Tatavla, he must have begun to strategize an escape to Europe and, in particular, to France.

The rising tensions that would lead to the First World War were only good for one industry: arms manufacturing.

▲ **SAILING TO TOTALITY** Antoniadi was Director of the British Astronomical Association's Mars Section when, in 1896, he boarded the *Norse King* with the Association's first-ever eclipse expedition to Norway. Unfortunately, the sky was cloudy on the day of the eclipse.

ALL IMAGES COURTESY OF THE WILLIAM SHEEHAN COLLECTION UNLESS OTHERWISE NOTED



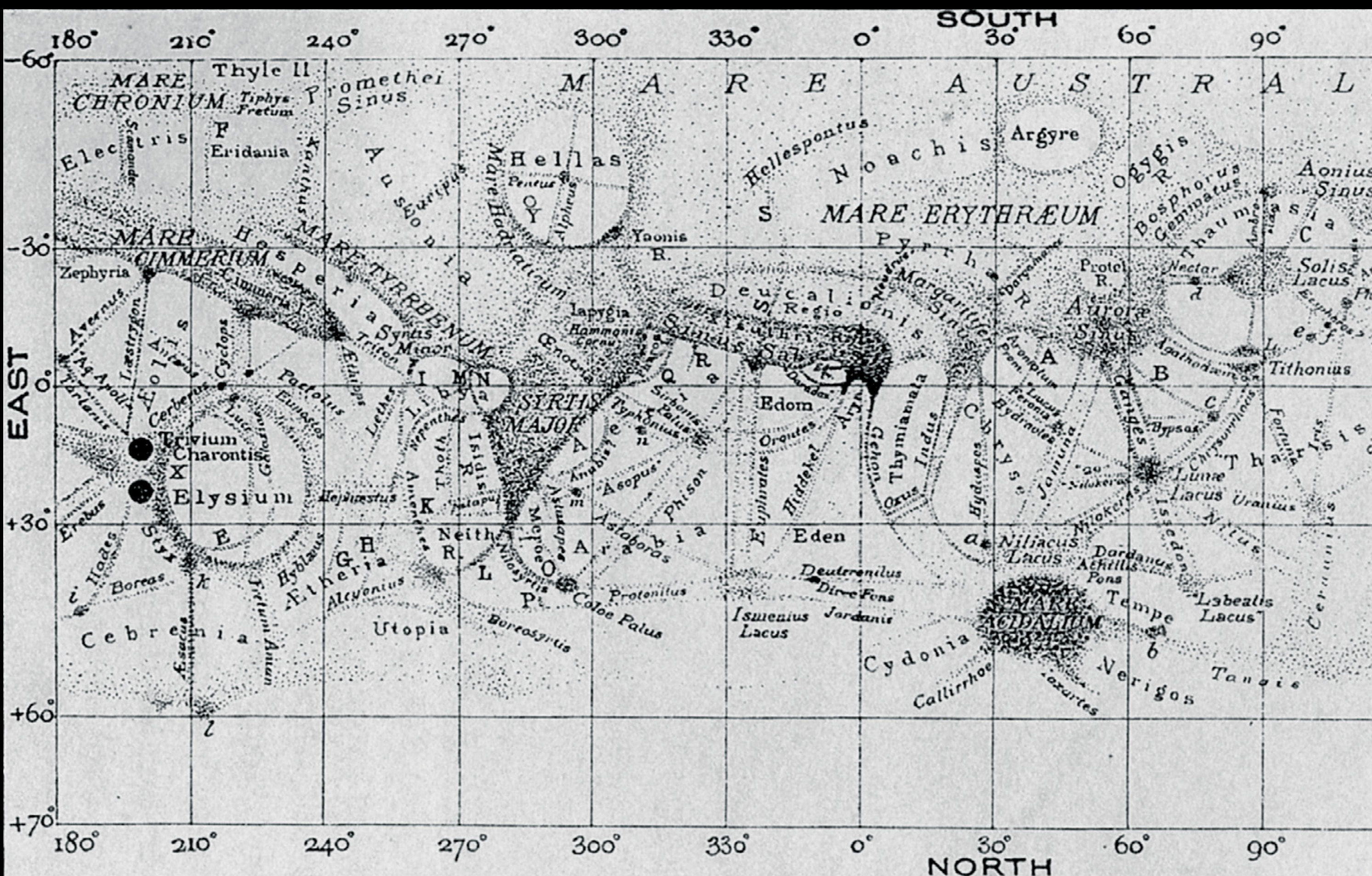
MAGICAL NIGHT Mars as rendered by Eugène M. Antoniadi on September 20, 1909, his first night with the 83-cm Meudon Observatory Grande Lunette refractor. The telescope is housed in the dome shown in this sketch by Antoniadi, which was published in the *Bulletin de la Société Astronomique de France* in 1927.

Curiously, Antoniadi was first cousin to the infamous arms dealer Vasileos Zacharias, better known as Basil Zaharoff, who became one of the wealthiest men in Europe through his corrupt business practices, which included selling arms to opposing sides in conflicts. (He also inspired numerous future villains, including Ernst Stavro Blofeld in the James Bond movies.) If Antoniadi made his reputation for his studies of the planet named for the god of war, his cousin worshipped a different war god. Zaharoff's greatest "success" was his zealous promotion of the British inventor Hiram Maxim's machine gun — a weapon probably responsible for more deaths than any other in human history.

As Zaharoff ranged over Europe looking for customers, Antoniadi occupied himself by producing excellent drawings of sunspots, Mars, Jupiter, and Saturn, made at the eyepiece of a small refractor likely set up at a family summer home in the Princes' Islands in the Sea of Marmara. He submitted his works to the Société Astronomique de France, founded by Camille Flammarion in 1887. Staggered by Antoniadi's talent, Flammarion hired the 23-year-old as an assistant astronomer at his observatory in Juvisy-sur-Orge in 1893, just two years after Antoniadi became a member of the Société. Flammarion's chateau housed a 9-inch refractor with which he observed the planets, especially Mars. In emigrating from Türkiye to France, it's possible that Antoniadi would have traveled on the famous Orient Express, perhaps in the company of Cousin Basil himself, who had his own private sleeping compartment.

A new era in Antoniadi's life had begun at this rail-stop town south of Paris. Antoniadi never lived at Juvisy-sur-Orge, residing instead in the 8th arrondissement of Paris, one of the most expensive parts of the city — an area that even today is noted for its luxury hotels and designer boutiques. Although he must have been eager to work for the famous French astronomer, the contract he signed paid a mere 300

▼ **SEEING AND BELIEVING** As Director the BAA Mars Section, Antoniadi was responsible for collating observations of the planet and producing maps summarizing each year's results. His first *Memoir of the Mars Section* described work done at the 1896 opposition, and it included this map which, as was typical of the time, is crisscrossed with canals.



francs per month (equivalent to about $1,400 today), while Flammarion also retained exclusive rights to publish any of Antoniadi's work in France. Although Antoniadi eventually came to resent this, at first all must have been sweetness and light. Flammarion was a fascinating figure, bubbling with ideas. He had just completed his magnum opus, *La Planète Mars* — a detailed summary of all the observations of the planet beginning with Galileo and running through the recent 1892 opposition. Under Flammarion's influence, Mars would become (and remain) Antoniadi's main astronomical interest. Before moving to France, Antoniadi had also joined the newly founded British Astronomical Association (BAA), and in 1896 he became director of its Mars Section and edited the Section's *Memoirs*.

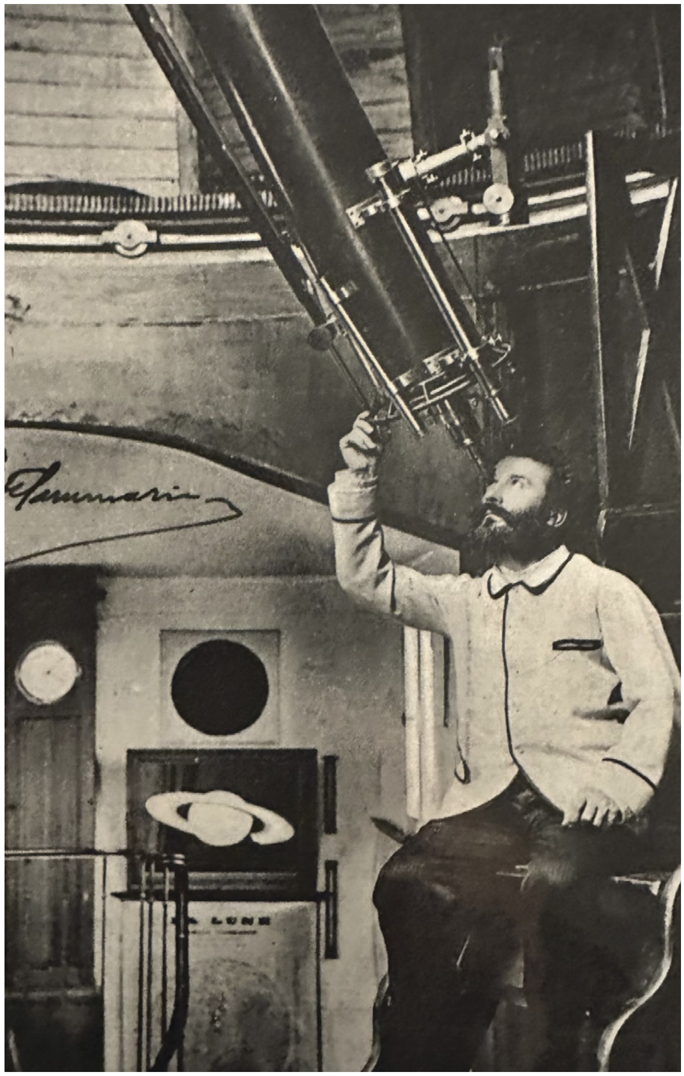
As is inevitable when two strong personalities interact at close quarters, Flammarion and Antoniadi began to fall out. It could have been anticipated from the start that the younger man would eventually grow weary of being dominated by the older. By 1900 Antoniadi wrote, "I cannot stand Flammarion anymore," and resigned his position.

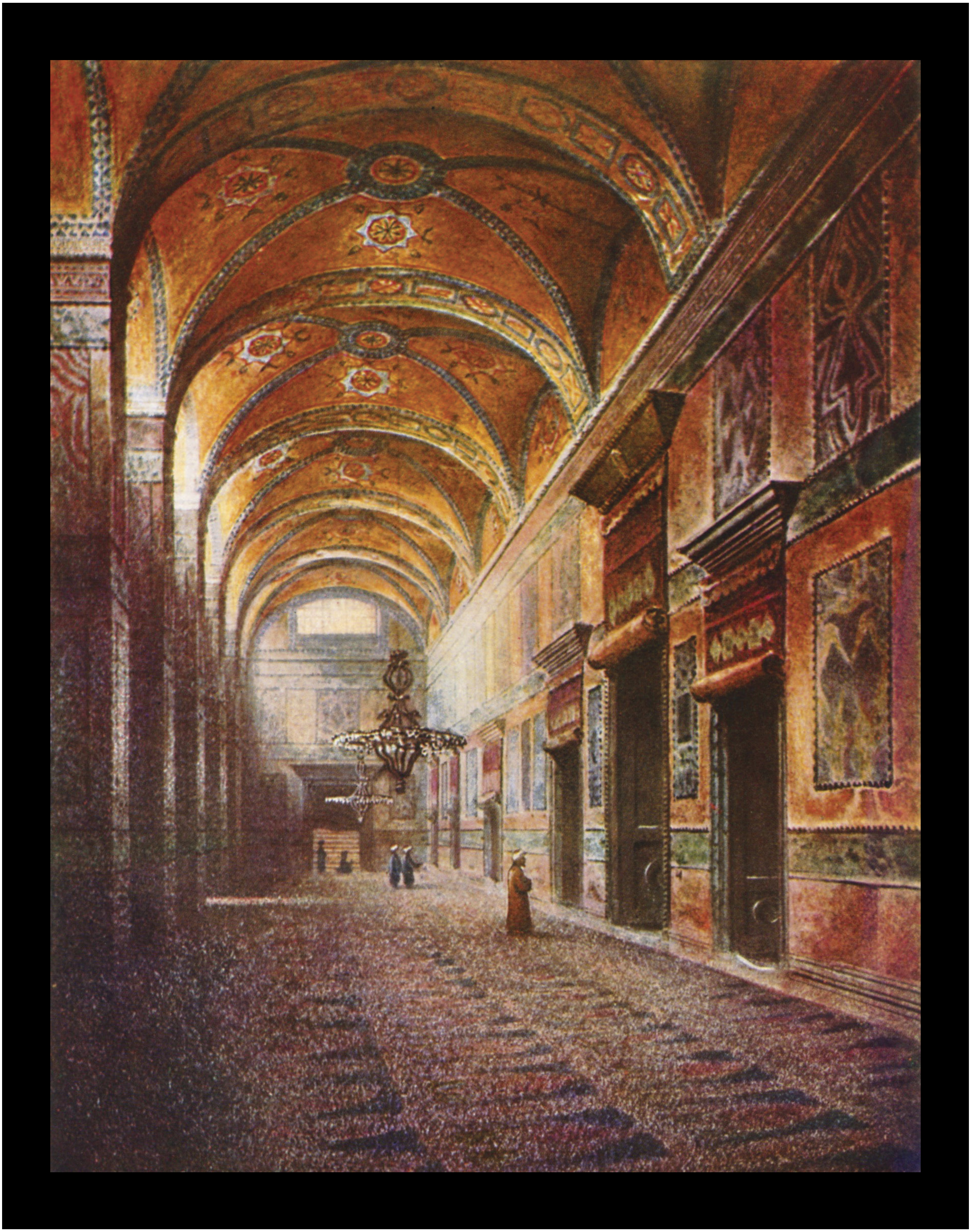
Rendezvous with Martian Destiny

Antoniadi achieved financial security and domestic happiness in 1902 through his marriage to Katherine Sevastupulo, who was also from a well-to-do Constantinople Greek family. They moved into a new residence, still in the 8th arrondissement, where they remained for many years. In addition, perhaps soured by his experience with Flammarion or just restless for change, Antoniadi seemed to have given up on astronomy. In its place, other interests came to the fore. He'd picked up chess in 1893 and now devoted serious attention to it, eventually attaining the level of a near-master, with some highly creditable matches to his name.

Most important, he embarked on an enormous project of drawing and (for the first time) photographing the interior of the Hagia Sophia mosque in Istanbul, leading to the publica-

▼ **KEEN-EYED OBSERVER** Arguably the 19th century's greatest popularizer of astronomy, and a dedicated observer of Mars, Camille Flammarion peers through the eyepiece of the 9-inch Bardou refractor at his private observatory at Juvisy-sur-Orge, France. Antoniadi served as his assistant from 1893 to 1900.





tion in 1907 of the three volumes of the *Ekphrasis tes Hagias Sophias* (Atlas of the Hagia Sophia). Here Antoniadi honed the already peculiarly realistic and meticulous drawing style he had exhibited in his BAA Mars maps, which included making extensive use of the time-consuming technique of *stippling* — rendering a scene with many tiny dots.

Upon returning from a chess tournament in Athens in the summer of 1909, Antoniadi found in his letterbox a note from Henri-Alexandre Deslandres, director of the Meudon Observatory, inviting him to Paris where he might observe that year's favorable opposition of Mars with the observatory's Grande Lunette. With an aperture of 83 cm (33 inches), it was the masterpiece of the French opticians Paul and Prosper Henry, and even today it remains the largest refractor in Europe. Lured out of astronomical retirement, his long apprenticeship at last over, Antoniadi now emerged as a consummate master, a prince among Mars observers.

That summer, as Mars approached its late-September opposition, the planet's features were largely obliterated by a great dust storm such as had never been seen before. Meanwhile, on Earth, the dust seems to have settled on a different storm. Perhaps because the two men no longer worked together, relations with Flammarion had improved significantly — to the point where Flammarion invited Antoniadi to set up his 8½-inch Calver reflector to monitor conditions on Mars from his lawn at Juvisy-sur-Orge. As August turned to September, the Martian dust had mostly cleared, and the planet's surface details began to re-emerge.

It was a magical night when Antoniadi at last took his place at the eyepiece of the Grande Lunette on September 20, 1909. Although most of the stars above Paris that evening were hidden behind a veil of fog, the air was exceptionally calm — a planet observer's dream. Antoniadi would never experience better seeing than he did that night. "The first glance cast on the planet," he wrote in an interim report for the *Journal of the BAA*, "was a revelation . . . . I did not believe that our present means could ever yield us such images of Mars."

The 1890s and 1900s were the heyday of the Martian canal controversy, and almost every Mars observer's chart was crisscrossed with linear canals — even the one Antoniadi had prepared for the BAA Mars Section. But now, with the Grande Lunette, the Red Planet presented a different appearance. Using a magnification of 320×, Antoniadi saw "a host of bewildering irregularities, all held steadily, and standing out with a boldness and definiteness defying description." He observed details that weren't linear, but instead "natural and logical, irregular and chequered." The south part of Syrtis Major was "a maze," the Mare Tyrrhenum appeared spotted "like a leopard skin."

Confronted with such a vast amount of Martian detail, an ordinary observer wouldn't have even attempted to draw the planet, and even Antoniadi noted that the perfect representation of every detail "was evidently beyond the power of man." But it was at this point that his savant-like qualities entered. Lurking in the darkness, with the shutter of the dome opened to the brilliant planet shining like a red-hot coal in the night sky, he concentrated on a particular small region and awaited the most favorable moments to catch the fine details and engrave them in his memory. He did the same with each adjacent region until, having stored all the shapes in their relative positions, he withdrew from the eyepiece and sat at a table where he quickly worked to set down everything on paper from memory — with exquisite results.

From Paris to Arizona

Just before that monumental night at Meudon, Antoniadi had renewed a long-dormant correspondence with the famous American astronomer and arch-canalist, Percival Lowell. Some years earlier, Antoniadi had tactlessly criticized some of Lowell's observations of Venus. He now apologized for the tone of his criticisms and promised to send Lowell the results of his work at Meudon. In response, Lowell lectured Anto-

◀ **HAGIA SOPHIA** This painting from Antoniadi's privately published (and now very rare) *Ekphrasis tes Hagias Sophias* (Atlas of the Hagia Sophia) is notable for its stippling technique, which he later used in many of his planetary drawings.

▶ **CAMERA SHY** Antoniadi, who rarely posed for photos, is shown here taking notes at the desk on the observing platform of the Grande Lunette. This is the only known photo showing Antoniadi observing.

niadi, whom he regarded as something of a neophyte, on the proper method of observing planets, which included the usual Flagstaff Observatory practice of stopping down the lens of the telescope in order to match its aperture to the size of the air cells passing overhead.

Ever since he began observing Mars in 1894, Lowell had seen no reason to doubt that the Martian atmosphere was almost always clear. Consequently, he failed to recognize the dust storm that had rushed across the planet that summer and instead ascribed its detail-obscuring effects to a case of bad seeing on Earth. Thus, he had made relatively sparse observations until late September, when he reported the discovery of two new "canals" on Mars. His drawing of September 30th shows the Syrtis Major region Antoniadi had represented so beautifully 10 days earlier. The difference in their styles is almost alarming.

Lowell did not receive Antoniadi's drawings until early November. Since Antoniadi had not stopped down his telescope's aperture as advised, Lowell thought that the younger astronomer had been betrayed by poor technique. In Lowell's opinion, Antoniadi's view of Mars must have been affected "by a fine imperceptible blurring which transforms the detail

▼ **UNDER THE DOME** A new copper dome protects the Grand Lunette, a century after Antoniadi's famous Mars observation. After a hiatus of several years, the telescope is now available for public viewing.

WILLIAM SHEEHAN

really continuous into apparent patches." Antoniadi thought this line of argument ludicrous. The two men debated for a while, but in the end, both remained set in their views. Lowell went to his grave believing in the canals, but the verdict of truth ultimately fell on Antoniadi's side.

Antoniadi's 1909 work on Mars represents his finest hour. He made further observations of Mars and Jupiter with the Grande Lunette in 1911, after which it was closed for some years due to repairs to the dome. During the First World War, he devoted a great deal of time to catching up on the backlog of BAA Mars reports and performed war-related work (what exactly is unknown) for which he received France's Legion of Honour. In 1917, he relinquished directorship of the Mars Section and resigned his membership in the BAA outright. It seems that the work of preparing the *Memoirs* and the stress of the war may have strained his delicate health. But then, Antoniadi always upheld the ideals of a true amateur. If an interest became a grind, he broke off from it. As he wrote to the Astronomer Royal, Frank Dyson, science "must be cultivated for its own sake, for the pure love of truth, rather than for the applause or profit that it brings." He took up chess again for a while, then returned to Meudon for the great opposition of Mars in 1924. He also began a long series of Mercury observations.

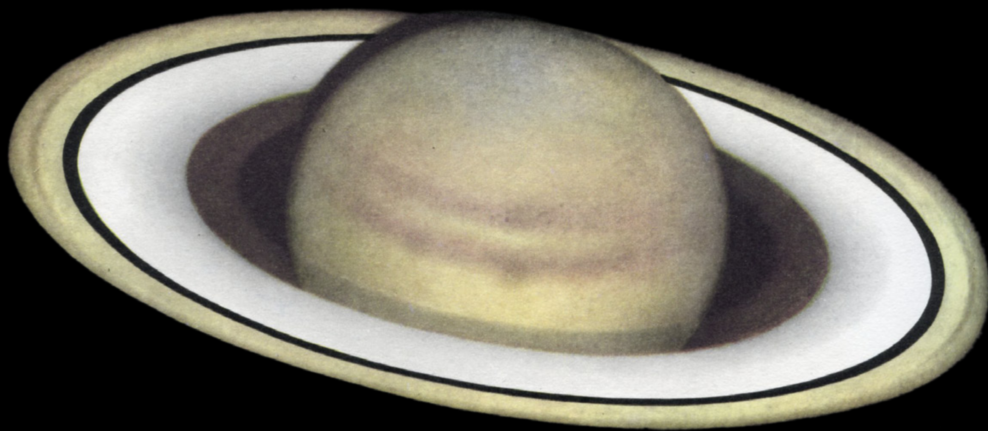
In June 1940 the Nazis occupied Paris. Antoniadi's health was beginning to fail, and despite being of comfortable means, he shared the lot of most Parisians during this period, living "by expediency, their meager rations eked out by food parcels from the country, their apartments heated by stoves filled with sawdust," as described by a diarist at the time.

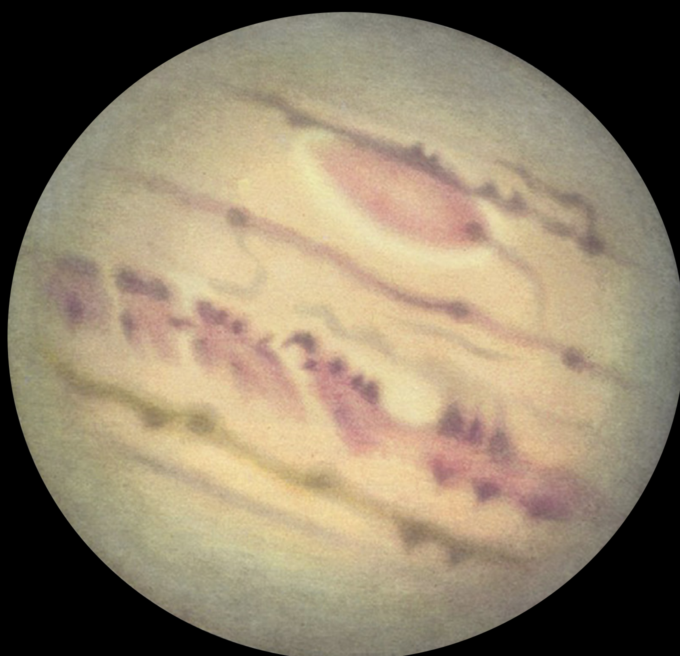
He continued to observe at Meudon and repaired each year to Juvisy-sur-Orge to mark, with colleagues, the anniversary of Flammarion's death in 1925. The younger generation of planetary observers regarded him with awe and dared not approach him. French astronomer Gérard de Vaucouleurs noted his "naturally curt manner," but also acknowledged that he was "by far the best planetary observer ever [with] an unsurpassed skill in transferring to paper fleeting telescopic views."

Although Antoniadi destroyed all his papers before he died in 1944 (possibly to avoid them falling into the hands of the Nazis), he nevertheless conveyed a sense of how he wanted to be remembered in a 1913 letter to the great American astronomer Edward Emerson Barnard:

". . . my only ambition is to defend the truth and write nothing susceptible of being overthrown. When we feel sure that our work will remain, that our representations of the heavenly bodies are accurate . . . then we may quit this world with the satisfaction of accomplished duty."

■ **BILL SHEEHAN**'s love of Mars began before the Mariner 4 flyby in 1965 and has persevered into the Perseverance era. He is author (with Jim Bell) of the modern classic, *Discovering Mars: A History of Observation and Exploration of the Red Planet* (University of Arizona Press, 2021).





PLANETARY WONDERS Although Antoniadi is best remembered for his work on Mars and Mercury, he also made observations of the other planets with the Grande Lunette, including Jupiter and Saturn. Indeed, one of his last observations was this one of Saturn, made on October 7, 1941. Both illustrations appeared in the 1964 work *The Flammarion Book of Astronomy*.

 by Camille M. Carlisle

Earth is the Eden of planets. Lush landscapes and vast oceans spread beneath a thin but indispensable skin of atmosphere, creating a haven in the barren wilderness of space. This little planetary paradise nestles in a self-made magnetic bubble, a *magnetosphere* generated deep within our world.

For decades, canonical wisdom has been that Earth's global magnetic field is a planetary defense system, a sneezeguard that shields our atmosphere from the relentless torrent of zippy charged particles streaming from the Sun. Without our magnetosphere, the thinking has gone, Earth might have only a meager whiff of air and be inhospitable to life.

Evidence comes from our neighbor Mars, whose wispy, carbon-dioxide atmosphere is less than 2% as dense as Earth's. Studies indicate that the solar wind has blown away most of the Red Planet's air over time, and that substantial loss began within the first billion years or so of the planet's existence — roughly around the time that Mars lost its global field (*S&T:* July 2018, p. 14). It seems likely, then, that the magnetic field's disappearance is why Mars is a frozen, arid, and lifeless world today.

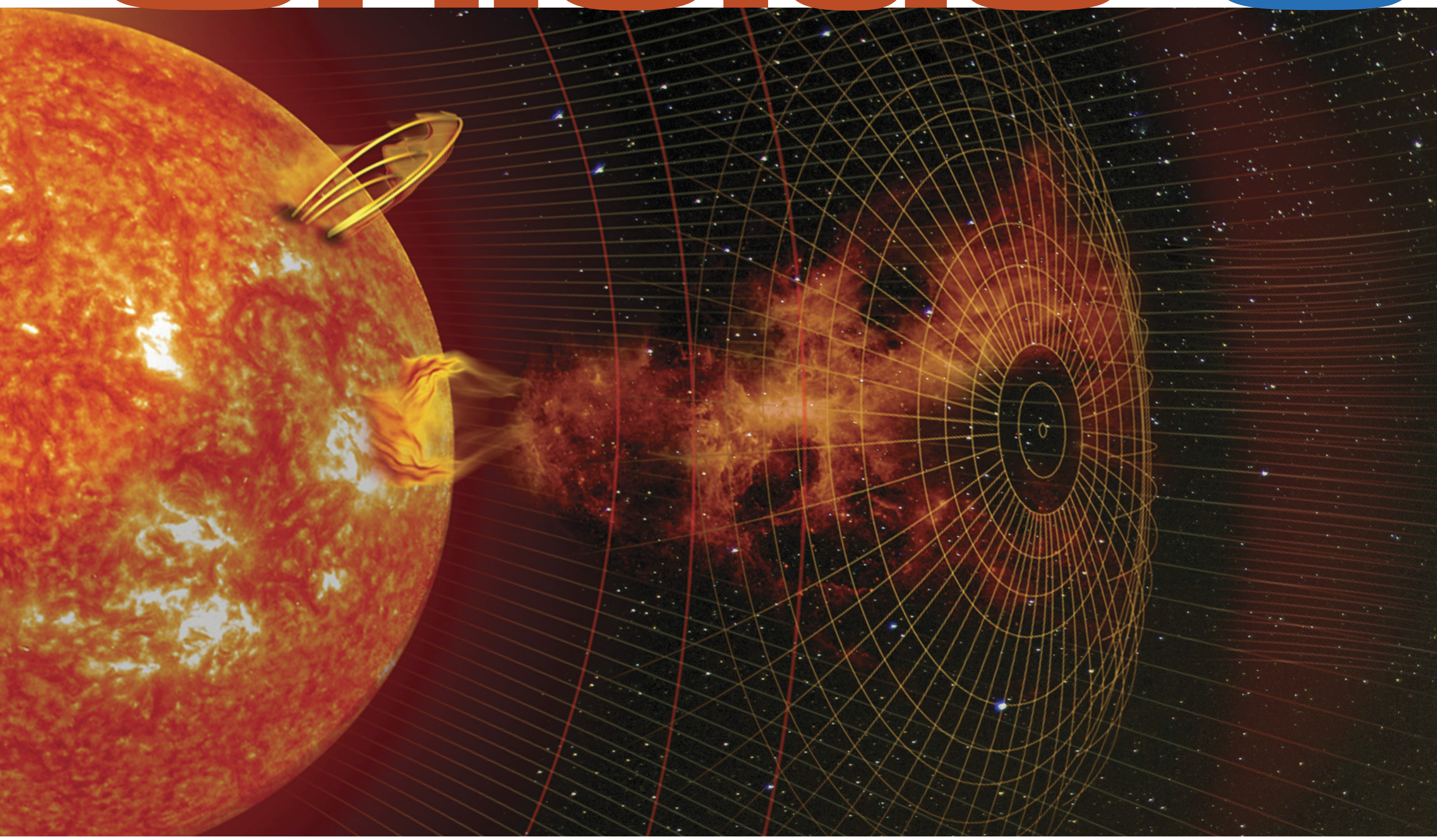
"I think that answer *might* be true," says planetary scientist David Brain (University of Colorado, Boulder). "But it's not certain to be true."

Anyone who contends that a magnetic field spells life or death for a planet's atmosphere must confront Venus. Venus's carbon-dioxide atmosphere is so thick that it suffocates the surface with a pressure 92 times greater than that at sea level on Earth. Yet like Mars, the planet doesn't generate its own magnetic field — much to the surprise of scientists in the mid-20th century, who had predicted otherwise.

Furthermore, measurements indicate that Venus, Earth, and Mars all lose roughly the same amount of ions to space. "If Earth's magnetic field is so darn important, then why does it have the same escape rate — at least of charged particles — that Venus and Mars do?" Brain asks. In fact, Earth's

ELENA11 / SHUTTERSTOCK, SOURCE: NASA

Shields U



atmosphere responds *more* than its neighbors do when the solar wind blows harder. "This question of 'does the magnetic field matter?' is now the question that gets me out of bed in the morning, scientifically."

Brain is one of an increasing number of scientists answering that rise-and-shine bell. Researchers are realizing that many factors determine whether a planet can hold onto its atmosphere, and only sometimes does the magnetic field play a definitive role. A 2021 review went so far as to conclude that, "based on the knowledge we have today, there is no reason to believe that a planet needs magnetization to protect its atmosphere."

Solar Squalls

Every second, the Sun blows 1 million tons of charged particles into interplanetary space. All the worlds in the solar system, from planets to comets, plow through this flow. When the solar wind encounters a magnetized world, the flow deflects around the body, like water around a rock in a stream. The region of disturbed water — or, in this case, charged particles — is called the magnetosphere.

Back in 1919, mathematical physicist Joseph Larmor first suggested Earth could sustain its global field thanks to an internal dynamo. The convective motion of an electrically conducting medium (like molten iron) will generate an electric field, which gives rise to a magnetic field, he realized. The energy that sustains the magnetic field comes from the fluid motions, which in turn are powered by the heat flowing outward from the cooling planetary core.

We know of seven worlds with active dynamos in the solar system: Mercury, Earth, the gas and ice giants, and Ganymede, Jupiter's largest moon. Each field has its own structure. We've also found evidence for dead dynamos on Mars and the Moon, with magnetic vestiges of their long-gone fields

We know of seven worlds with active dynamos in the solar system: Mercury, Earth, the gas and ice giants, and Ganymede, Jupiter's largest moon.

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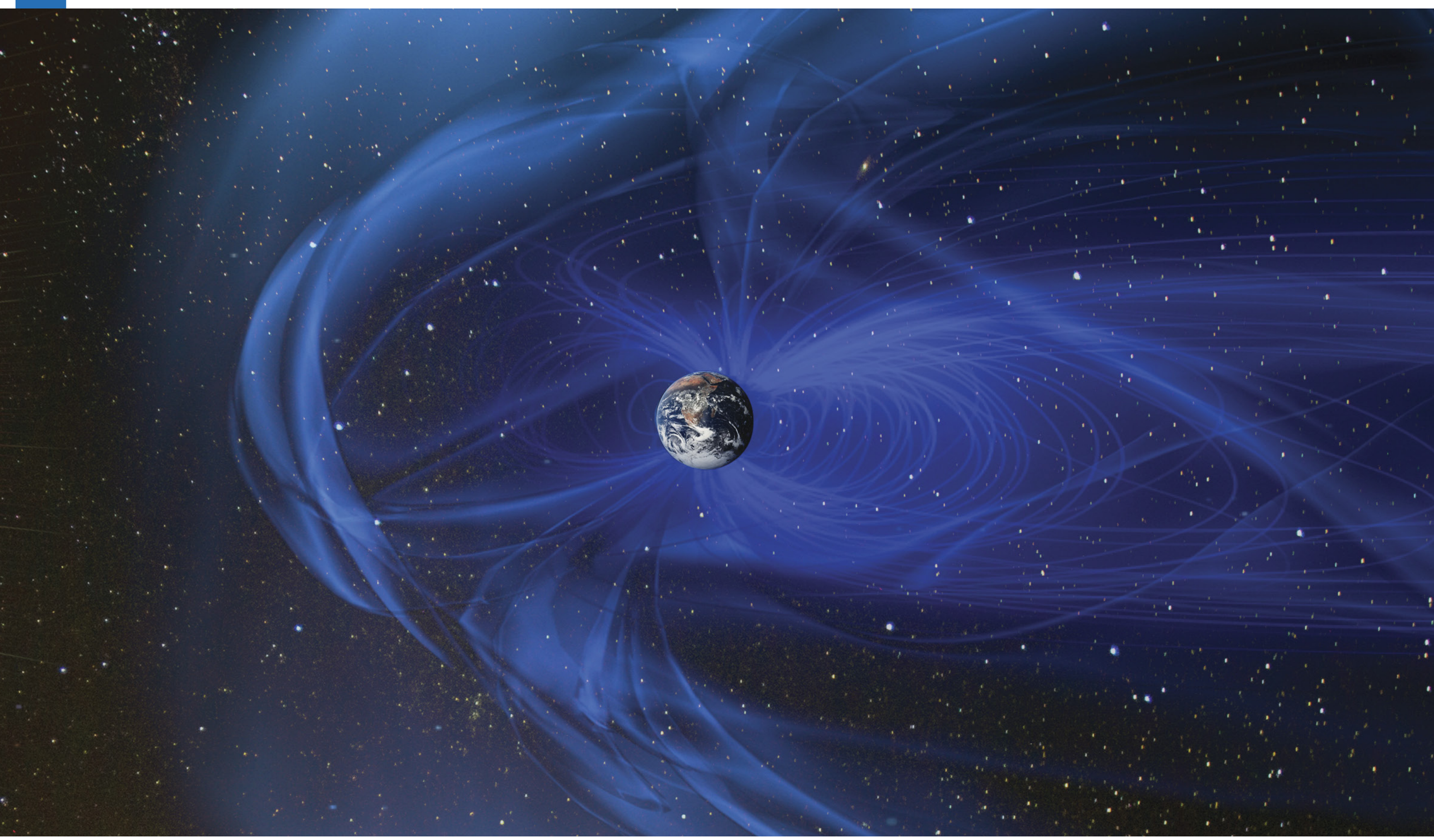
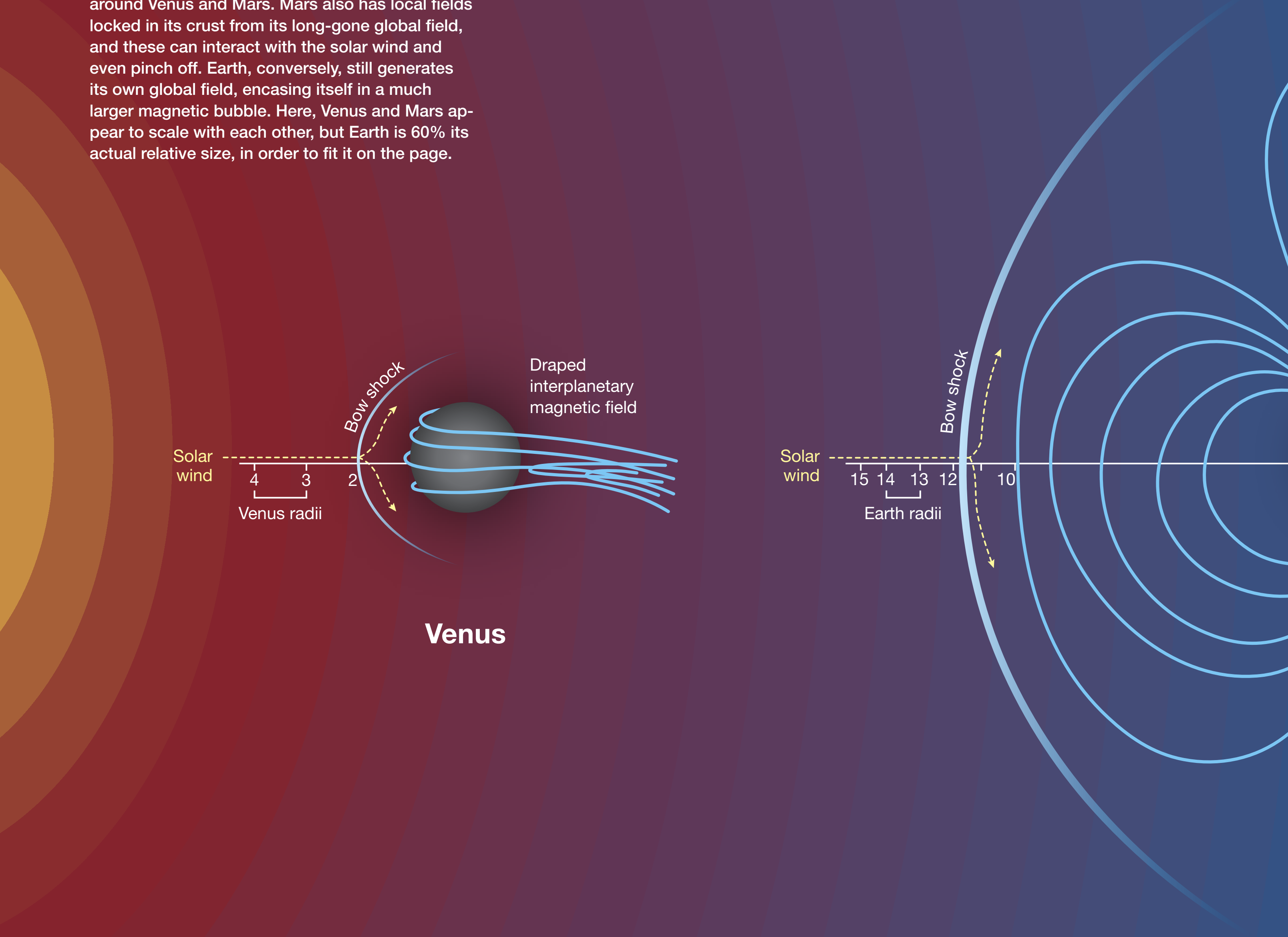
Scientists are second-guessing the role magnetic fields play in protecting planets.



MAGNETOSPHERES Venus, Earth, and Mars are each sheathed in magnetic fields that stream out behind their nightsides. The field carried by the solar wind creates the small magnetospheres around Venus and Mars. Mars also has local fields locked in its crust from its long-gone global field, and these can interact with the solar wind and even pinch off. Earth, conversely, still generates its own global field, encasing itself in a much larger magnetic bubble. Here, Venus and Mars appear to scale with each other, but Earth is 60% its actual relative size, in order to fit it on the page.



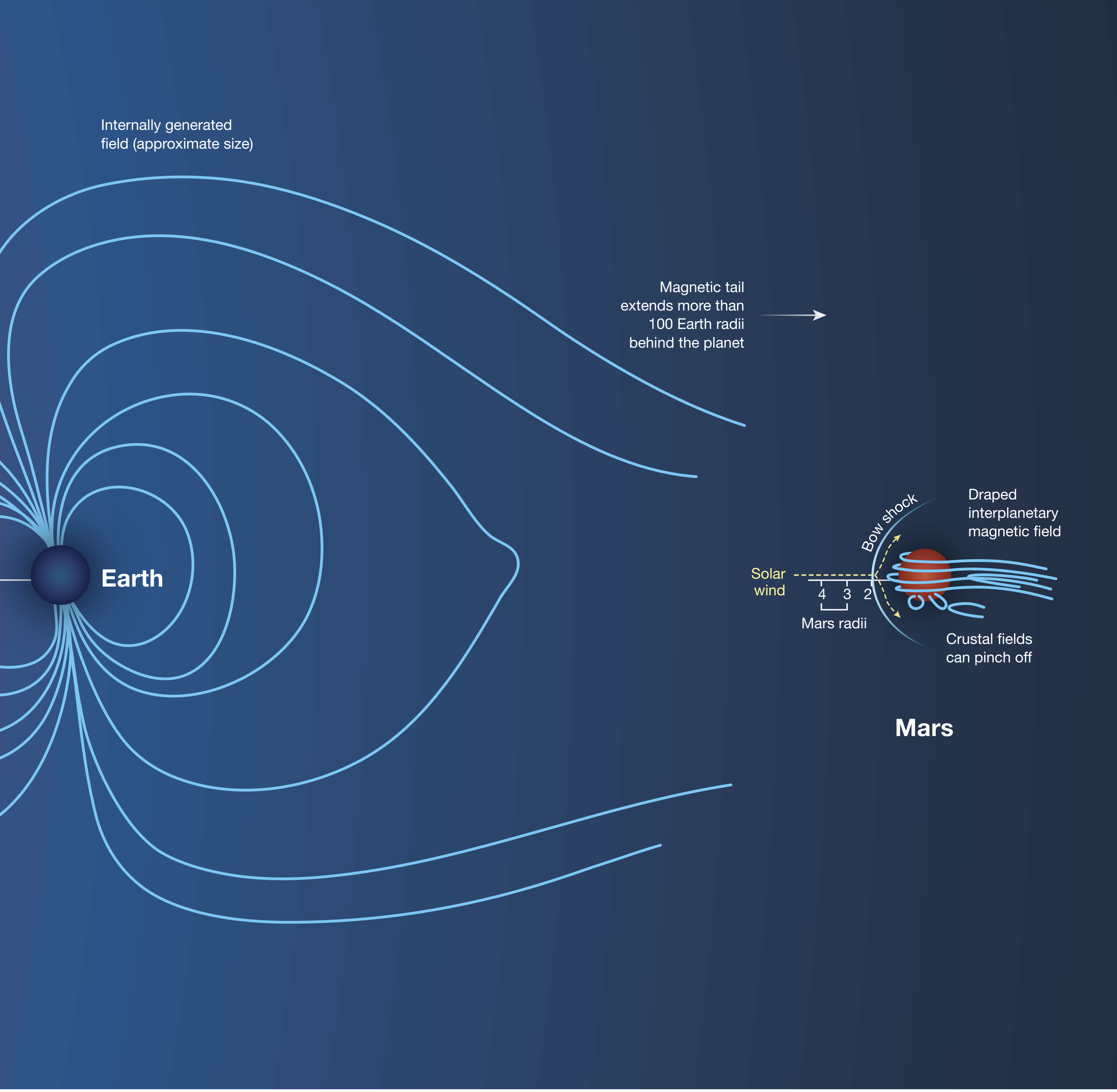
Venus radius = 0.95 Earth radius
Mars radius = 0.53 Earth radius

locked into surface rocks. (Earth has these crustal fields, too, although here we sometimes call them magnetic anomalies.)

We don't know whether Venus had a global field. Rocks can preserve magnetic fossils so long as the rocks aren't too hot, explains Shannon Curry (University of California, Berkeley). Volcanism has flooded the Venusian surface, and it can erase magnetism. But surface temperatures today don't exceed the critical threshold to wipe away frozen-in fields. Although spacecraft haven't detected crustal fields at Venus yet, our measurements are limited, she says — for instance, we haven't flown a magnetometer close enough to the southern hemisphere to have picked up any fields there.

Venus and Mars may not have *intrinsic* fields today, but they do have a different kind of magnetic shield, one given them by the Sun. A planet's upper atmosphere is largely ions, which means it's full of charged particles. When the solar wind hits the ionosphere, the magnetic field the wind carries induces a current, making the charged particles flow. This

BEATRIZ INGLESSIS / *S&T*



flow generates an *induced magnetic field*, which deflects the wind. The wind and the field it contains then drape around the planet, "similar to what one might envision happening to cooked pasta noodles when thrown at a basketball," Brain wrote in 2021.

An induced magnetosphere is much smaller than an intrinsic one. Those around Venus and Mars extend to only a fraction of the planet's radius. Earth's intrinsic field, on the other hand, is about a dozen times wider than the planet itself. Nor will an induced field matter on the planet's surface — you can't navigate with it.

But it will matter in the atmosphere.

Sitting Ducks

A planet can lose atmosphere in several ways. A blast of plasma from the Sun can tear material off or drive currents through it, heating the gas so much that the world's gravity can't hold onto it anymore. Sunlight can overheat it,

too. Even the magnetic field itself can dump energy into the atmosphere, says Ofer Cohen (University of Massachusetts, Lowell), if the space environment shakes the field up enough to send waves through it in just the right way.

Against this onslaught, the magnetic field provides a limited defense. The field only controls charged particles coming in or going out, things like protons and ionized oxygen. It cannot protect against radiation. Nor can it hold onto neutral atoms and molecules. But planets larger than Mars are too massive to let go of their neutral particles, which hunker lower in the atmosphere, protected by gravity. For Venus and Earth, ion-driven escape is the only option.

Even so, Earth's magnetosphere helps as much as it hurts. In some cases, the field can spit energy from the solar wind back out, but in others — particularly when the planet's field and the solar wind's match up in just the right way — the field stores the energy and deposits it in the atmosphere. (Think aurorae.)

An intrinsic magnetosphere also makes the planet a much larger target, diverting more energy from the solar wind into the ionosphere. And the field funnels energy to specific regions — on Earth, that's the poles — which can help heavier ions escape. In fact, for our planet, the net effect may *increase* how much energy the solar wind can dump into the atmosphere.

Simulations support this surprising conclusion. In 2018, Herbert Gunell (now at Umeå University, Sweden) and others explored what would happen to fictitious Venus, Earth, and Mars analogs with different magnetic fields. They found that the planets had similar loss rates whether unmagnetized or strongly magnetized (as strongly as Jupiter, which has a field 20,000 times stronger than Earth's). But for fields similar to the modern Earth's, the escape rate was a wee bit higher than in the unmagnetized scenario.

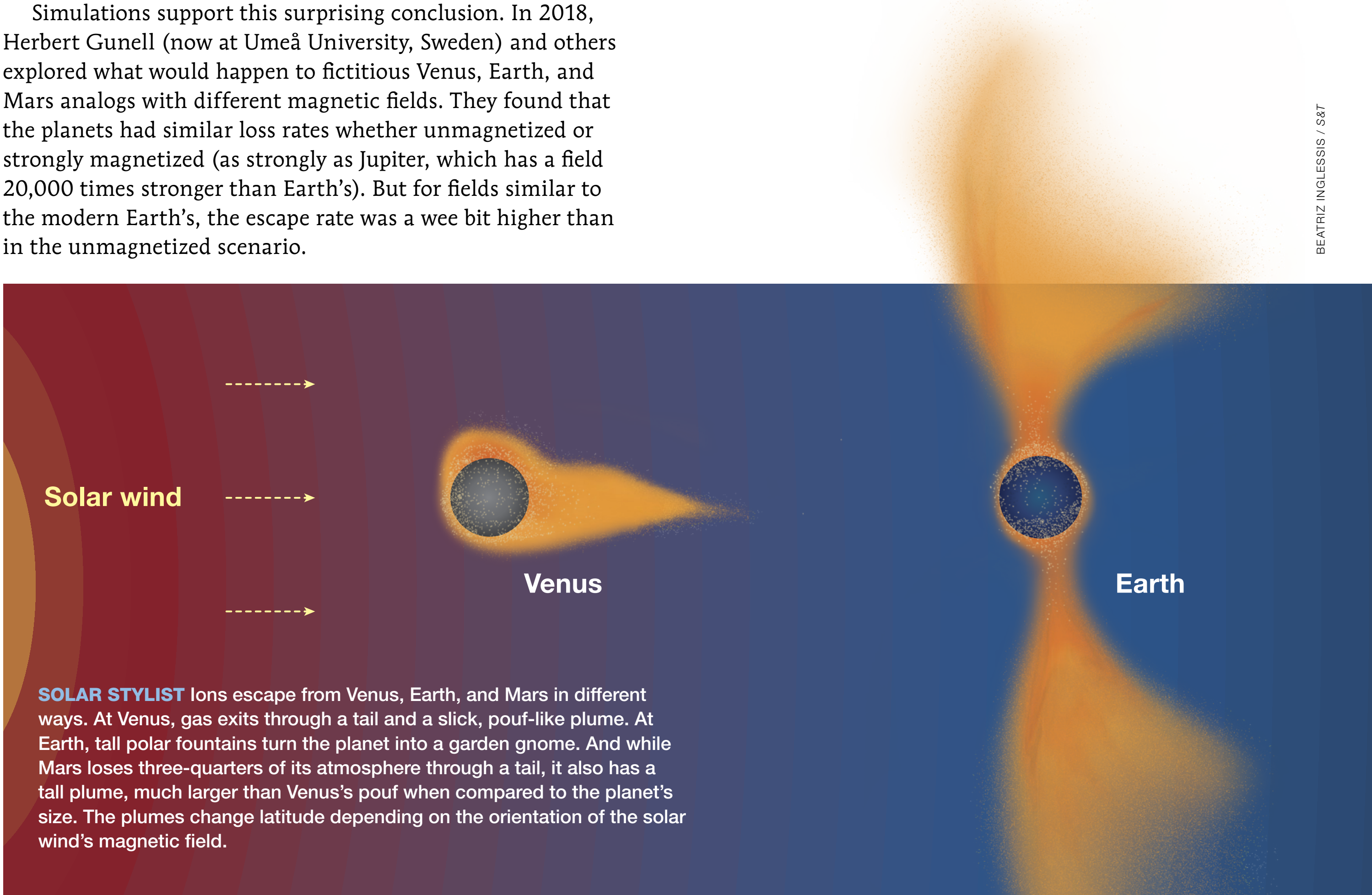
Planetary Perm

Venus, Earth, and Mars all lose atmosphere differently. Earth suffers a steady leak from its poles. At Venus, the atmospheric loss looks more like your hair would if you stuck your head out the car window while gunning it on the highway, Curry says. And Mars has "party hair" — a big mohawk plume that sometimes comes out of the pole and other times from closer to the equator, depending on the orientation of the solar wind's magnetic field.

The solar wind's properties matter a lot. The field it carries is stronger at Venus's distance from the Sun (0.7 astronomical unit) than it is at Earth (1 a.u.) or Mars (1.5 a.u.), and it slicks Venus's atmospheric hair back as a result. (It's even stronger at Mercury's roughly 0.38 a.u., but the pipsqueak Iron Planet doesn't have an atmosphere.)

It's unclear how much Venus has suffered due to its proximity to our star, but it *has* lost gas. Based on the ratio of hydrogen to deuterium in its skies, we think nearly all of the planet's water has fled to space. The likely reason is that Venus was so hot under its greenhouse-gas blanket that the water evaporated into the atmosphere, where sunlight could break the molecules apart and leave the hydrogen atoms vulnerable to space-weather robbery (*S&T:* Oct. 2021, p. 12).

"Escape has been really important at Venus," Brain says.



BEATRIZ INGLESSIS / S&T

SOLAR STYLIST Ions escape from Venus, Earth, and Mars in different ways. At Venus, gas exits through a tail and a slick, pouf-like plume. At Earth, tall polar fountains turn the planet into a garden gnome. And while Mars loses three-quarters of its atmosphere through a tail, it also has a tall plume, much larger than Venus's pouf when compared to the planet's size. The plumes change latitude depending on the orientation of the solar wind's magnetic field.

"It has been more important at Venus and Mars than it has been at Earth, if you're interpreting the same isotope signatures of all three planets." That fact might be an argument in favor of an intrinsic magnetosphere's importance.

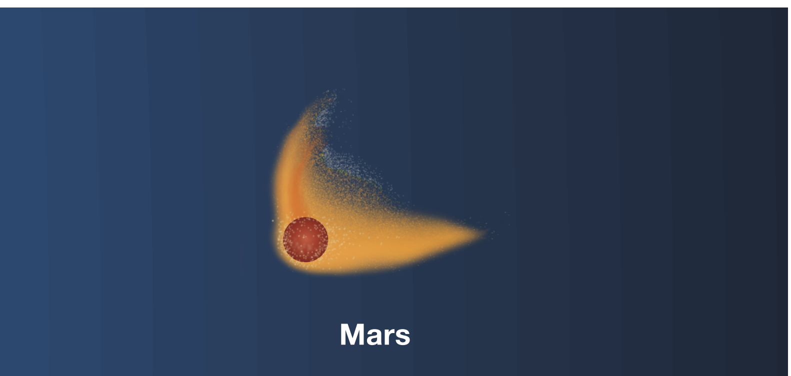
Mars still provides the best case for a shield effect, but it's a holey shield. The crustal fields do offer some protection. The strongest ones lie in the southern hemisphere, and when they're on the dayside — pointed at the Sun and the impinging wind — there's a bit less atmosphere escaping than when they're on the nightside, Curry says. On the other hand, she adds, the crustal fields may make the atmosphere more vulnerable by fluffing it up via magnetic pressure.

More important, though, is Mars's size: It's only half as wide and one-tenth as massive as Earth. It therefore cannot hold on to its atmosphere as strongly, and so what little atmosphere exists is puffed up — nothing like Venus's slick look. A diffuse, inflated atmosphere is a vulnerable atmosphere. The solar wind hits this extended haze and easily carries it away.

Mars's size likely doomed the planet at least as much as the loss of its magnetic field. "I don't want to say it never had a chance," Curry says. But it's so small that it can lose atmosphere in ways Venus and Earth can't. "Whether it had a magnetic field or didn't, it already had different physics."

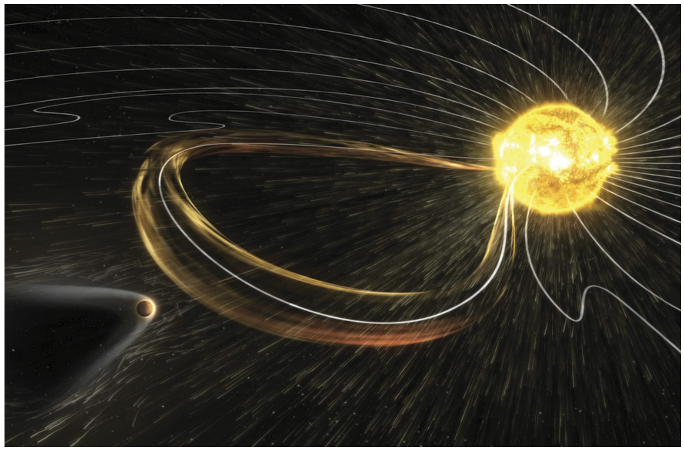
How Close Is Too Close?

Not only does a magnetic field control where a planet's atmosphere escapes from, it can also affect the atmosphere's makeup: The field controls the escape of certain chemical species more than others, as well as the influx of energy and charged particles from the solar wind. But when it comes to preserving an atmosphere, many other factors may have a larger impact. The planet's size and distance from its host star, the orientation of its magnetic field, the space weather it experiences, the type of atmosphere it has, and when (and how quickly) that atmosphere builds up, are all important, says Cohen.



NASA SCIENTIFIC VISUALIZATION STUDIO

Mars has "party hair" — a big mohawk plume that sometimes comes out of the pole and other times from closer to the equator.



▲ **TARGET PRACTICE** Artist's concept of a solar eruption headed for Mars. The sinuous white lines represent the solar magnetic field.

A planet could replenish its atmosphere by coughing out volcanic gases as quickly as it loses stuff to space. Venus may have started its runaway greenhouse process so early that by the time the global field shut down (assuming it had one), the atmosphere was too large for the solar wind to remove it. Plus, Venus is bigger than Mars. "It seems like yes, the magnetic field did shield the atmosphere to some extent" on Mars, Cohen says. "But we are not in a position to generalize that statement to any planet."

The space environment has a huge impact on atmospheric loss, he emphasizes. Our terrestrial trio share a fairly clement interplanetary climate — although solar spitballs can hit one world and miss the others. But we find exoplanets in a range of environments around other stars, some more harrowing than others.

When close to its star, a planet will be baked in heat and buffeted by stellar gusts. The planet Trappist-1e, for example, ostensibly lies at the right distance from its star to sustain liquid water on its surface, if it has the right atmosphere. But Trappist-1 is an active red dwarf, unleashing searing radiation and magnetic outbursts. Because the star is puny, its habitable zone girds it tightly: 1e snuggles up at a distance less than 8% the size of Mercury's orbit.

Astronomers have yet to detect an atmosphere on a terrestrial world around a red dwarf, and Cohen suspects that many of these exoplanets have no hope of keeping their atmospheres. Some even orbit within their star's *Alfvén surface*, which marks where the stellar wind is still connected to the star — essentially, the planets are moving through the star's outer atmosphere, the wispy but blisteringly hot corona. Within this boundary, the stellar wind can overwhelm and disrupt the planet's magnetosphere, constantly penetrating the world's atmosphere.

The location of the Alfvén surface depends on the strength

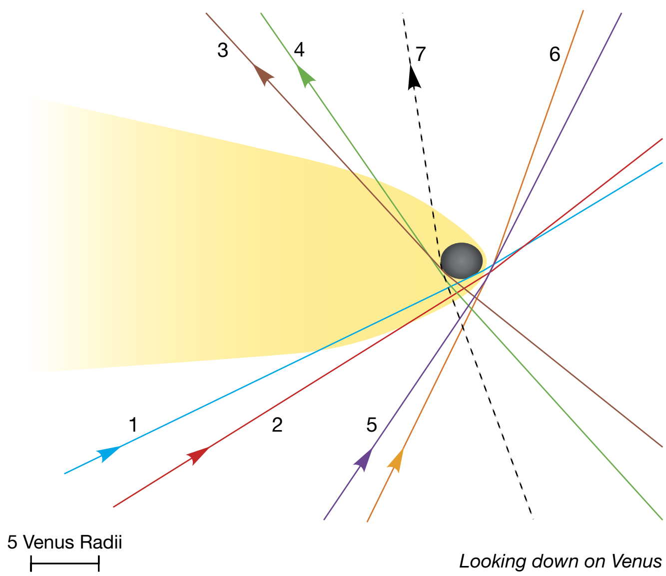
of the star's magnetic field. For the Sun, the boundary lies very close to our star, somewhere between five and 20 solar radii, or roughly 0.05 a.u. — well within Mercury's orbit. But for an active red dwarf, the boundary lies much farther out, several dozen times the star's radius. Trappist-1's corona, for example, reaches partway into its habitable zone.

Not all red-dwarf planets are cursed, though. Work by Cohen and others indicates that the calmer red dwarf TOI-700 has a mild stellar wind. The terrestrial planets in its habitable zone — which lies beyond the star's Alfvén surface — might maintain their atmospheres.

Lay of the Land

One problem with tackling how a magnetic field affects atmospheric loss is that we don't know the escape rates at Venus and Earth all that well. "We know more about Martian atmospheric escape than we do about any other planet," says Curry, who's the principal investigator of NASA's MAVEN mission, a key provider of those measurements. "And while we take pride in that, I'm also horrified." There's never been a mission dedicated to studying Earth's atmospheric escape, she laments, and the spacecraft data we have from Venus are limited.

In a quest to change that, Curry is leading an effort with the Parker Solar Probe to study our planet's fraternal twin. Parker is whizzing past Venus during a series of flybys intended to nudge the spacecraft into a tighter solar orbit. Some of these passes take the craft through Venus's atmospheric tail. Parker's measurements make previous instruments sent to Venus look like the first generation of smartphones, so the flybys present a unique opportunity.



▲ **PARKER FLYBYS** The Parker Solar Probe has buzzed Venus several times (shown here from above the planet's north pole), each trajectory taking it tantalizingly close to the planet. Flybys 1 through 5 occurred 2018–2021; flyby 6 happened in August 2023. The seventh flyby, scheduled for November 2024, will explore the tail region right behind Venus.

Preliminary results indicate both that there's more stuff in Venus's outflow and that it's moving faster than expected.

Curry, Brain, and others are also looking forward to NASA's Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) mission. Set to launch on a Blue Origins rocket in summer 2024, ESCAPADE will join MAVEN to provide multi-angle, real-time coverage of the Red Planet's response to the solar wind. (In a rare instance of cross-disciplinary work, the agency's heliophysics division is funding the mission.) NASA has also extended MAVEN's mission through 2031 to support a planned sample-return mission, so it might even be possible to send a third orbiter while both craft are still active.

Meanwhile, Brain, Cohen, and a team of two dozen scientists from a half-dozen disciplines are tackling the questions of whether and when a magnetic field matters and under which conditions a planet can retain its atmosphere. Their ultimate goal, Cohen says, is to create a landscape of all the possibilities, so that we can say, "If a planet is *here* under these conditions, it should have a sustainable atmosphere, and the magnetic field maybe helped. And if it's *here*, it didn't." The team recently calculated what happens when they plop a Mars-like planet around a red dwarf. Preliminary results indicate the escape rates increase, but the researchers are still exploring which processes have the greatest impact and exactly how much loss occurs.

Cohen has also explored whether we could detect an exoplanet's intrinsic magnetic field. Astronomers have discovered thousands of worlds around distant suns by detecting the minuscule dip in the star's light as the exoplanet passes in front of it. If the planet has a strong self-made field, then the magnetosphere will create a bubble with a different density in the space-weather environment. This bubble should refract the radio emission from the star in a unique way as the planet transits, potentially revealing the field to radio telescopes such as LOFAR.

Nevertheless, Cohen thinks that we should keep our gaze on Venus, Earth, and Mars to understand planetary magnetic fields and atmospheres. "Understanding why these three planets are so different will give us 90% of our understanding about how [terrestrial] planets form in the universe," he says. "My strong belief is that we should use our solar system as the main constraint for any problem we try to solve for exoplanets. So if something doesn't work for what we know for the solar system, I don't think it can work elsewhere."

"I am sure that there are situations for which the magnetic field is really important, and I'm sure that there are situations for which it is not," says Brain. "And there are situations that are kind of right on the hairy edge. . . . For now, I'm kind of declaring victory by helping the community understand that this is a question — that it's not settled science."

■ When asked if she wants to go to Mars, Science Editor **CAMILLE CARLISLE**'s favorite reply is, "No way. I mean, have you *seen* it?"

BEATRIZ INGLESSIS / S&T

OBSERVING
December 2023

1 DAWN: Look low in the southeast before sunrise to see Venus blazing 4½° left of Virgo's lucida, Spica. Go to page 46 for more on this and other events listed here.

3 EVENING: The waning gibbous Moon and Regulus rise in the east-southeast with some 3½° between them. Follow the pair as they climb during the night.

8 DAWN: Turn to the southeast to take in the sight of the waning crescent Moon a bit more than 2° above Spica. Venus at lower left completes the tableau.

9 DAWN: The slim lunar crescent and Venus adorn the southeastern horizon before sunrise; around 3½° separates the duo.

11 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:38 p.m. PST (see page 50).

13–14 ALL NIGHT: The Geminid meteor shower is expected to peak. The Moon is one day past new and won't interfere with viewing. Turn to page 48 for tips on how best to experience this meteor shower.

14 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:27 p.m. EST (6:27 p.m. PST).

17 EVENING: Face southwest to see the waxing crescent Moon 2½° below left of Saturn.

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 6:17 p.m. EST.

21 EVENING: High in the southwest the waxing gibbous Moon sits some 6° below right of Jupiter. The gap between the pair closes throughout the night as they sink toward the western horizon.

21 THE LONGEST NIGHT OF THE YEAR in the Northern Hemisphere. Winter begins at the solstice at 10:27 p.m. EST (7:27 p.m. PST).

28 DAWN: Look low in the west to see the waning gibbous Moon in Gemini. Around 2° separates it from the brighter of the Twins, Pollux.

29 DAWN: The Moon, now three days past full, visits Cancer, where it gleams some 3½° right of the Beehive Cluster (M44).

31 DAWN: High in the west-southwest the waning gibbous Moon is in Leo, where it hangs about 2½° upper right of Regulus.

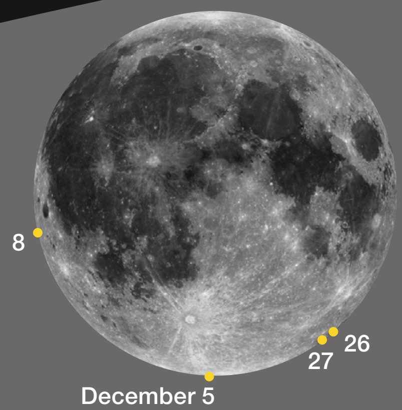
31 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:23 p.m. PST.
—DIANA HANNIKAINEN

▲ Geminid meteors streak above the European Southern Observatory's Very Large Telescope facility in December 2012. The Small and Large Magellanic Clouds are visible in the upper left-hand side of the image. ESO / G. LOMBARDI

DECEMBER 2023 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

LAST QUARTER
December 5
05:49 UT

NEW MOON
December 12
23:32 UT

FIRST QUARTER
December 19
18:39 UT

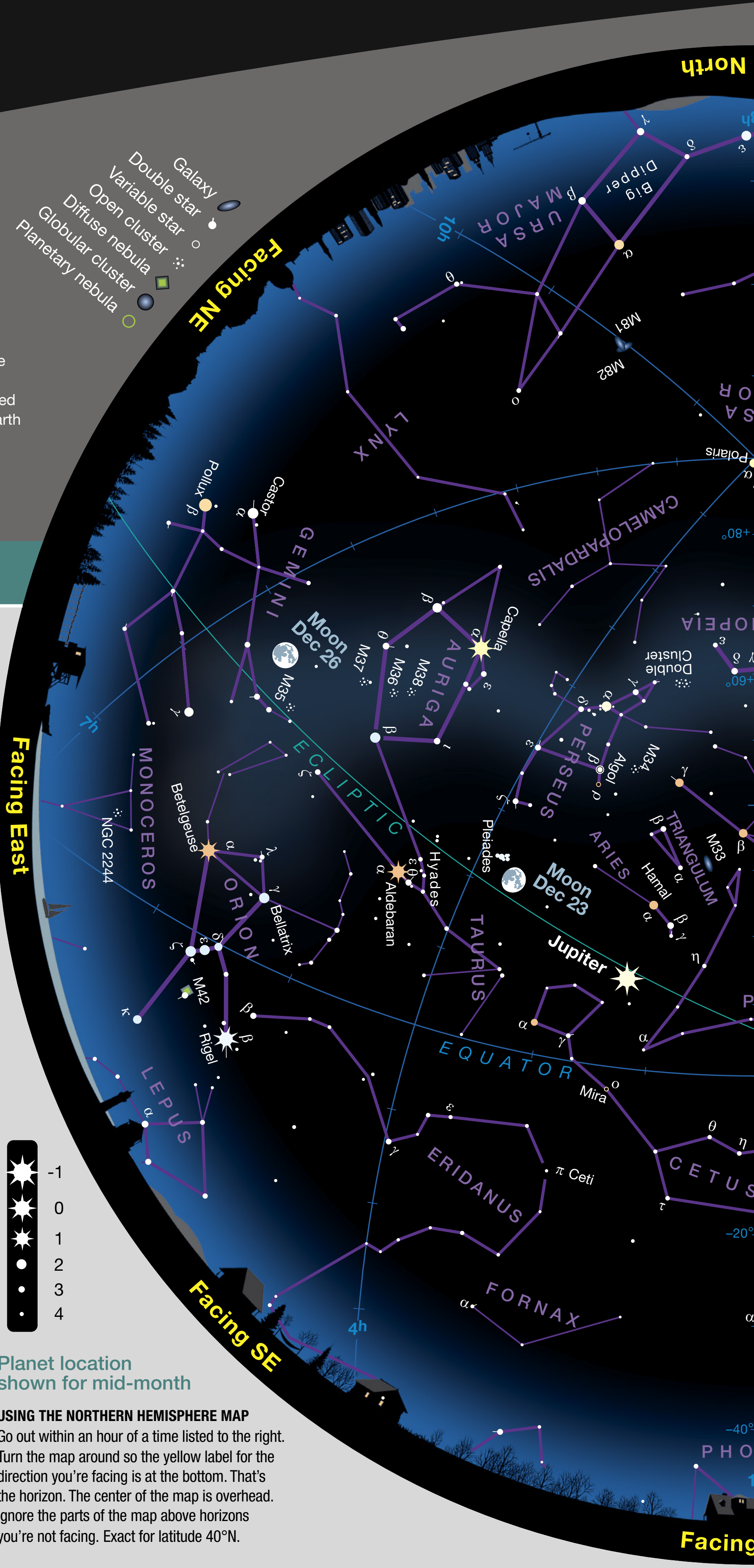
FULL MOON
December 27
00:33 UT

DISTANCES

Apogee	December 4, 19ʰ UT
404,346 km	Diameter 29′ 33″
Perigee	December 16, 19ʰ UT
367,901 km	Diameter 32′ 29″

FAVORABLE LIBRATIONS

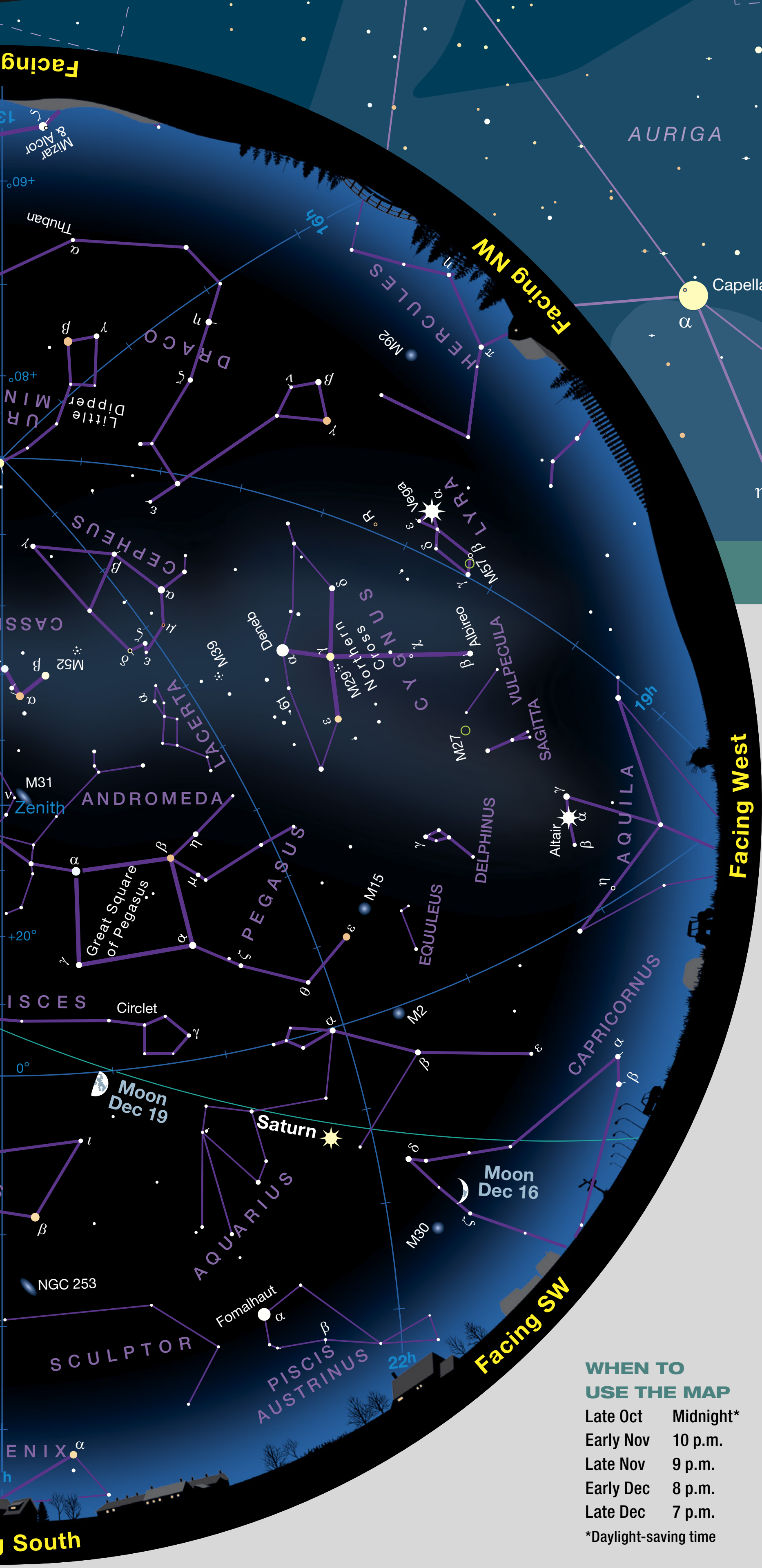
• Cabeus Crater	December 5
• Lacus Autumni	December 8
• Oken Crater	December 26
• Lyot Crater	December 27

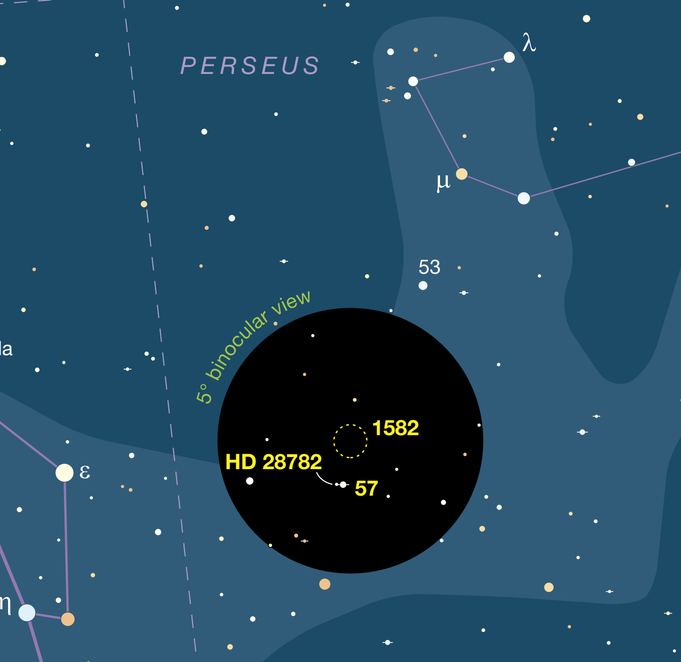


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





WHEN TO USE THE MAP

Late Oct	Midnight*
Early Nov	10 p.m.
Late Nov	9 p.m.
Early Dec	8 p.m.
Late Dec	7 p.m.

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Adrift in the Sea of Stars

I suspect we all have different tolerances for poetry, but nautical metaphors for the night sky — the sea of stars, peering into the deeps — really work for me. Like the sea, the night sky is vast, mysterious, and romantic, and it calls to me like a watery horizon.

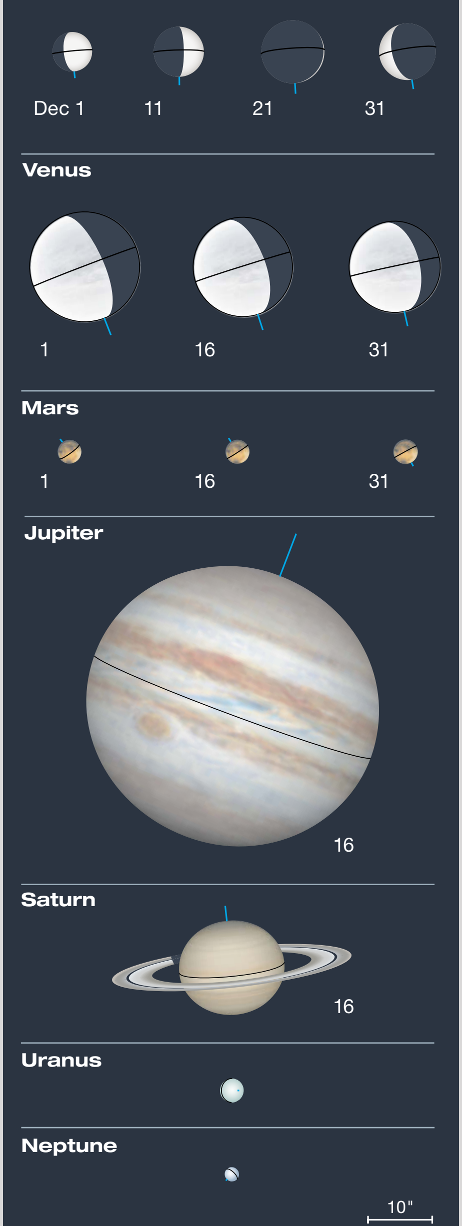
The celestial ocean has its far-flung and seemingly lonely outposts. One of my favorites is the open cluster **NGC 1582**, in the eastern reaches of Perseus, the Hero. The cluster sits halfway between the prominent stars of Perseus and Auriga, the Charioteer, like a desert island far from any continent. I like to get there by following the jagged chain formed by Lambda (λ), Mu (μ), and 53 Persei; NGC 1582 lies 3° southeast of 53 Persei.

At 7th magnitude, NGC 1582 has a reasonably high total brightness, but its apparent diameter of 24′ means the cluster's light is spread thinly. I find that the cluster "pops" best in my 7×50 binos, where its light is more concentrated. Jumping up to my 15×70s reveals two curving arcs of stars, like a loosely wound barred spiral galaxy and a dark center that appears empty. All of this is set in the stretch of Milky Way that runs northwest from Auriga into Perseus.

While you're in the neighborhood, look about ¾° south of NGC 1582 to find the lovely multiple star **57 Persei**. This close pair consists of a 6.1-magnitude primary and a 6.8-magnitude companion that form a true gravitationally bound system. With a separation of 121″, they are easily split even at 7×. That binary forms a wide optical double, only coincidentally aligned, with 7.4-magnitude **HD 28782**, which lies about 7′ almost due east.

■ As much as he admires the science of astronomy, **MATT WEDEL** is content to let aesthetic appreciation take the wheel for most of his observing.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk until the 12th then at dawn starting on the 30th • **Venus** visible at dawn all month • **Mars** is lost in the Sun's glare • **Jupiter** visible at dusk and sets before dawn • **Saturn** transits around sunset and sets in the evening.



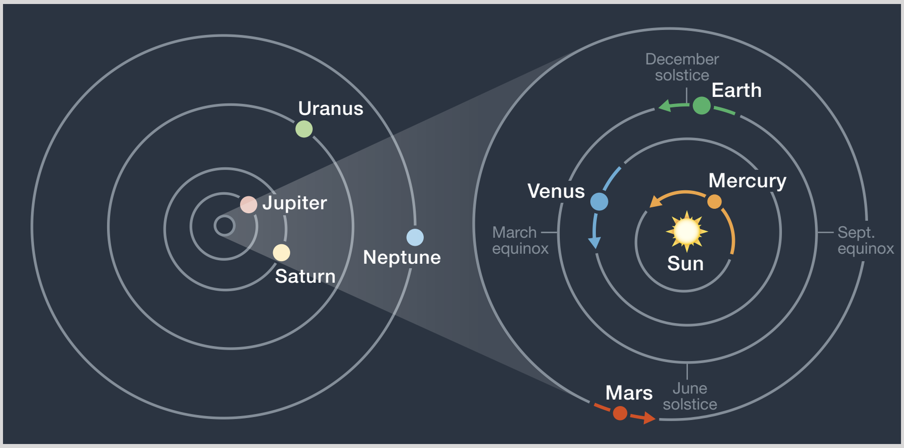
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during December. The outer planets don't change position enough in a month to notice at this scale.

December Sun & Planets

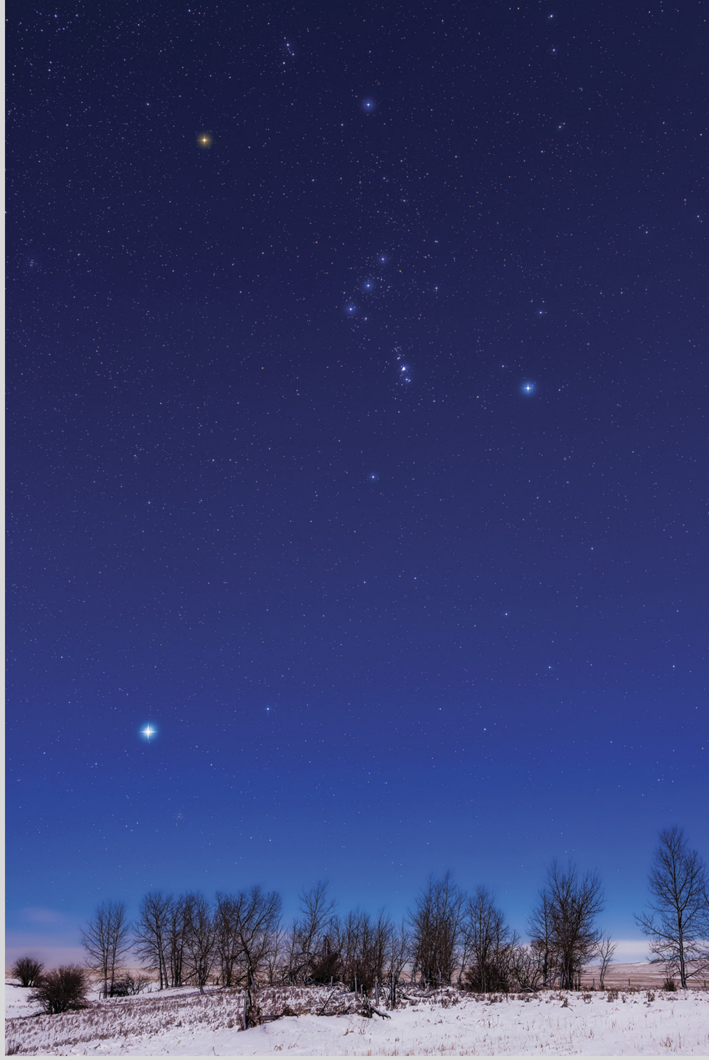
	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h\ 25.7^m$	–21° 40′	—	–26.8	32′ 26″	—	0.986
	31	$18^h\ 37.8^m$	–23° 09′	—	–26.8	32′ 32″	—	0.983
Mercury	1	$17^h\ 55.3^m$	–25° 51′	21° Ev	–0.5	6.2″	72%	1.091
	11	$18^h\ 34.0^m$	–24° 32′	19° Ev	–0.1	7.8″	40%	0.861
	21	$18^h\ 11.8^m$	–21° 47′	5° Ev	+4.6	9.8″	2%	0.683
	31	$17^h\ 26.9^m$	–20° 06′	17° Mo	+0.8	8.9″	23%	0.759
Venus	1	$13^h\ 36.7^m$	–7° 46′	43° Mo	–4.2	17.1″	68%	0.975
	11	$14^h\ 21.7^m$	–11° 43′	41° Mo	–4.1	16.0″	71%	1.044
	21	$15^h\ 08.6^m$	–15° 21′	40° Mo	–4.1	15.0″	75%	1.111
	31	$15^h\ 57.4^m$	–18° 26′	38° Mo	–4.0	14.2″	78%	1.176
Mars	1	$16^h\ 09.4^m$	–21° 15′	4° Mo	+1.4	3.7″	100%	2.503
	16	$16^h\ 55.6^m$	–23° 00′	8° Mo	+1.4	3.8″	100%	2.469
	31	$17^h\ 43.5^m$	–23° 55′	12° Mo	+1.4	3.9″	99%	2.427
Jupiter	1	$2^h\ 19.5^m$	+12° 31′	149° Ev	–2.8	48.0″	100%	4.111
	31	$2^h\ 13.4^m$	+12° 09′	117° Ev	–2.6	44.1″	99%	4.467
Saturn	1	$22^h\ 13.8^m$	–12° 46′	83° Ev	+0.9	16.9″	100%	9.824
	31	$22^h\ 21.5^m$	–11° 59′	54° Ev	+0.9	16.2″	100%	10.281
Uranus	16	$3^h\ 08.5^m$	+17° 18′	146° Ev	+5.6	3.8″	100%	18.792
Neptune	16	$23^h\ 42.1^m$	–3° 18′	91° Ev	+7.9	2.3″	100%	29.868

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



Bright Orion Sights

Winter's mighty Hunter is a sight to behold.



As cold weather arrives in the Northern Hemisphere, a brigade of stellar brightness climbs into the evening sky. Let's focus our attention on the many naked-eye splendors found in the brightest constellation of this (or any) season: Orion, the Hunter.

Before diving into Orion's individual delights, take a moment to appreciate the main pattern of the constellation as a whole. It includes two stars of 1st magnitude and five more of 2nd magnitude. The Hunter is delineated by a stellar duo that marks his flaming shoulders, a second pair of stars that indicate his radiant knees, three stars in a row that represent his Belt, and the collections of fainter lights that outline the Sword hanging from his Belt.

One of Orion's finest sights is the fire-colored variable star Betelgeuse, Alpha (α) Orionis. It's among the brightest orange stars in the heavens, but if you've been following the night sky closely over the past few years, you'll recall its recent spectacular fade. Starting in October 2019, Betelgeuse dimmed from its normal magnitude +0.5 to as faint (by my estimate) as 1.8, before brightening to normal again last April. This sudden dramatic activity doesn't necessarily indicate that the red supergiant is about to become a brilliant supernova. However, most astronomers think that is likely to happen within the next 100,000 years, which is actually "very soon" on a cosmological time scale. The lesson is clear: Keep watching!

Orion's second fascinating bright star is Rigel, Beta (β) Orionis. Despite its Beta designation, it shines steadily at magnitude +0.1, which means it's almost always slightly brighter than Alpha Orionis. However, the two stars have markedly different colors — Rigel has a touch of blue, which most people find obvious when shifting their gaze between it and Betelgeuse. And supergiant Rigel is vastly more luminous. If the two suns were the same distance from Earth, Rigel would shine four times brighter than Betelgeuse! They only *appear* similarly bright because Rigel is nearly twice as far away.

One of Orion's most distinctive features is its Belt. This trio of equally spaced, 2nd-magnitude stars forms an almost straight line only 3° long. Scanning east to west, the Belt is delineated by Alnitak, Alnilam, and Mintaka — also known as Zeta (ζ), Epsilon (ε), and Delta (δ) Orionis, respectively. Mintaka holds the distinction of being the brightest star near the celestial equator, situated less than ½° south of that imaginary line. And because the Belt is so near the celestial equator, from many latitudes it appears vertical when it rises due east on December evenings.

The region surrounding Orion's Belt is peppered with fainter stars, a handful of which lie at the threshold of naked-eye visibility under dark skies. Binoculars will reveal dozens of these gems — a collection cataloged as the huge open cluster Collinder 70.

Of course, no discussion of Orion would be complete without mention of his Sword, shining "like burnished stellar steel," as legendary deep-sky observer and *Sky & Telescope* columnist Walter Scott Houston described it. Compared to the Belt, however, the Sword is less distinct — its brightest star is 3rd-magnitude Iota (ι) Orionis. And as wondrous as this compact, north-south collection of stars is, its fame is mostly due to the presence of the splendid Orion Nebula, M42. Although the nebula is visible without optics, its true magnificence is reserved for telescope users.

▲ **WINTER WONDER** December evenings herald the arrival of winter's most distinctive constellation — Orion, the Hunter. Home to seven stars of 2nd magnitude or brighter, Orion stands out boldly even amid the season's array of bright constellations, including the night sky's brightest star, Sirius, at lower left.

ALAN DYER

Let's conclude our brief survey of Orion with another recollection from Scotty as he gazed up at the winter sky: "How can a person ever forget the scene . . . it may well be beauty in its purest form."

■ **FRED SCHAAF** began his first *Sky & Telescope* column with a lyric from the Jethro Tull song "Orion": "Your faithful dog shines brighter than its lord and master / Your jeweled sword twinkles as the world rolls by."

To find out what's visible in the sky from your location, go to skyandtelescope.org.

Spica Welcomes Venus and the Moon

A busy month features several appealing lunar conjunctions.

FRIDAY, DECEMBER 1

Stars are like rocks in the sea — they're immobile, and so they have to wait for the fish to come to them. The luckiest stars are the handful of bright ones arrayed along the ecliptic, where they patiently wait for a visit from a planet or the Moon. The second-brightest ecliptic star is **Spica**, in Virgo. (Aldebaran in Taurus is #1.)

As December opens, Spica welcomes the brightest planet of all, **Venus**. The honorary Morning Star gleams at magnitude –4.2 and has been near Spica for several days. On this particular morning it's at its closest — just a touch more than 4½° to Spica's left. They rise together around 3:30 a.m. local time and climb to an altitude of 20° just before the start of astronomical twilight. That's when the fun begins. Venus is more than 100 times brighter than the 1st-magnitude star, so how deep into twilight can you hold Spica in view by using the planet's proximity as your guide? What about with binoculars?

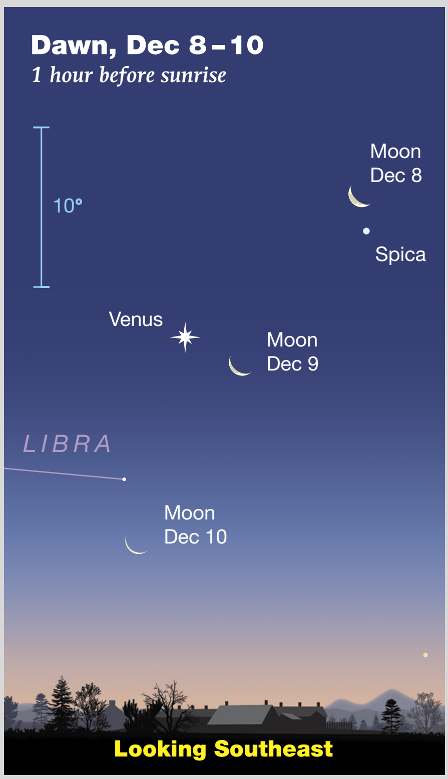
FRIDAY, DECEMBER 8

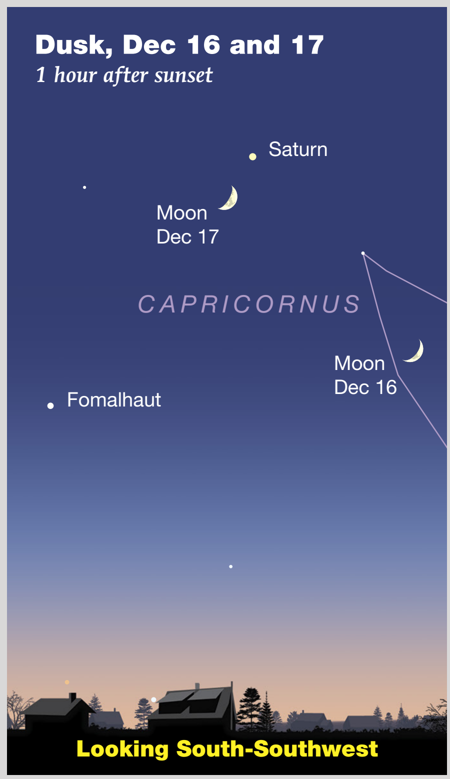
Exactly one week after **Spica** welcomes Venus, the star plays host to the **Moon**. Early risers will get to see the 20%-illuminated, waning lunar crescent hovering just 2° above Virgo's leading light. The Moon is slowly approaching the star as dawn begins, and the farther west you are, the narrower the gap between them will get. By the time twilight brightens the sky for observers on the West Coast, the separation is just 1½°. Unfortunately, when they're at their absolute closest (a bit more than 1° apart), it will be daytime all across the Americas. Of course, no matter where you are, you can't miss the gleaming presence of **Venus** sitting 11° left of Spica and adding an extra jolt of luster to the scene.

SATURDAY, DECEMBER 9

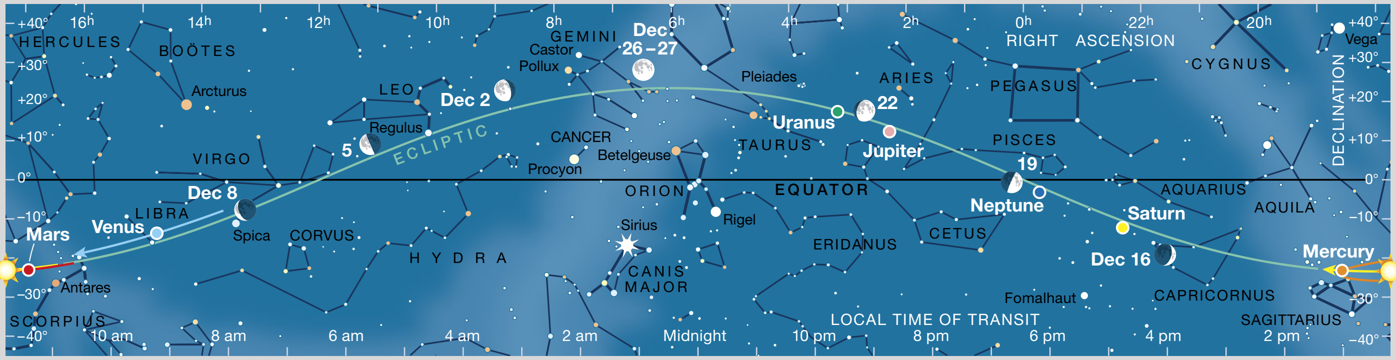
For a vivid reminder of just how quickly the **Moon** races along the ecliptic, try to compare yesterday morning's conjunction with this one. If you manage to catch both, you might be surprised to see that the waning crescent has covered the entire distance between **Spica** and **Venus** in just 24 hours, so that it's now positioned 3½° below right of the brilliant planet. Indeed, the Moon shifts eastward against the stars by its own diameter every hour. However, Spica isn't entirely out of the picture — it completes a temporary, elongated right triangle with the two fleeting "fish," Venus and the Moon.

Meetings between the Moon and Venus are often the celestial highlight of any given month — there's just something deeply satisfying about seeing the night sky's two brightest luminaries side by side. The sight is especially





▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.



▲ The Sun and planets are positioned for mid-December; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

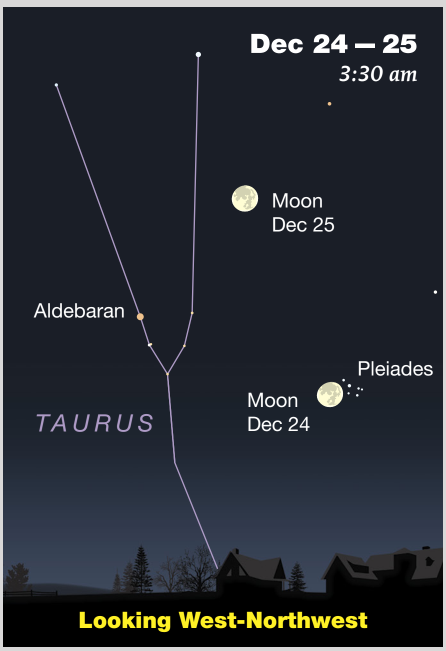
wondrous when the Moon is a narrow, earthlit crescent, as it is this morning when it's just 13% illuminated. Remember: The narrower the crescent, the brighter the earthshine.

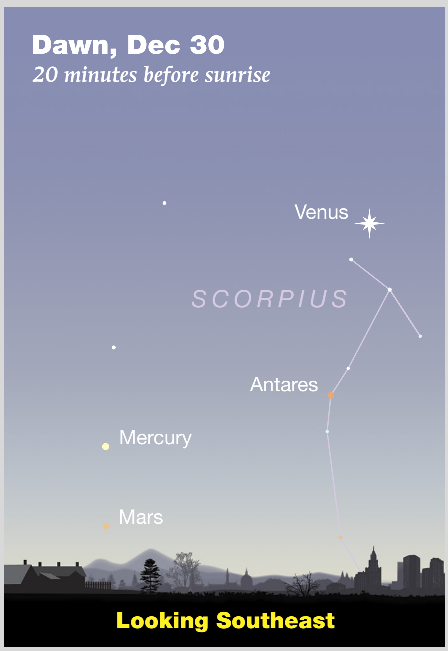
SUNDAY, DECEMBER 17

Dawn's waning crescent **Moon** has transitioned into dusk's waxing crescent, and on this evening it pairs up with **Saturn**. The famed Ringed Planet glows at magnitude +0.9 from its perch a bit more than 2½° above right of the Moon. Interestingly, you can use the phase of the Moon to gauge where a planet is in its apparition. When the waning crescent is nearby, the planet is beginning a new apparition; and when it has a conjunction with the full Moon, it must be close to opposition. The proximity of tonight's waxing crescent indicates Saturn is approaching the end of its run as it inexorably drifts sunward towards its February 28th solar conjunction. And though you won't be able to see it, on that date it'll be the new Moon that passes near Saturn. (This Moon-planet trick doesn't work for Mercury or Venus, however.)

FRIDAY, DECEMBER 22

Moving right along, the **Moon** approaches within 3° of magnitude –2.7 **Jupiter** as the pair sink toward the west-northwestern horizon at around 3 a.m. local time. And what phase is the Moon? It's a waxing gibbous, which indicates Jupiter is a little past opposition. And sure enough, the gas giant hit that mark just last month, on November 3rd. If you're not inclined to get up early to see this pairing, you don't have to miss out entirely. On the evening of the 21st, the Moon will be 7° to Jupiter's right, and at nightfall on the 22nd, it will sit roughly 6½° to its left. A couple of pretty good consolation prizes, I'd say.





SUNDAY, DECEMBER 24

Continuing the trend of early-morning conjunctions, your reward for getting up before dawn today will be seeing the **Moon** parked on the outer edge of the **Pleiades** cluster in Taurus. At its closest, the waxing gibbous will be less than 1° from the cluster's brightest star, 2.9-magnitude **Alcyone**. Sounds great, right? But here's the thing. The Moon is very bright (92% illuminated) and will be setting when it's closest to the Pleiades. So, for the best view, you should try to catch the pair a little before they're closest, and you'll also need binoculars to retrieve most cluster stars from the Moon's overwhelming glare. Our satellite's path along the ecliptic in Taurus takes it south of the cluster, so it'll be close to the Pleiades for several hours before it gradually begins to drift away.

■ Consulting Editor **GARY SERONIK** enjoys chasing the Moon even on cold December nights.

Moon-free Geminids

A fine year for meteor showers has a final hurrah.

This has been an optimal year for meteor watching with basically moon-free skies for each of the major showers — the Lyrids, Perseids, Orionids, and now the Geminids. This display, which derives from dust shed from the asteroid 3200 Phaethon, is active through mid-month and peaks on the night of December 13–14. It's the strongest display of the year, and you can expect more than 100 Geminids per hour under a dark and *moonless* sky. No problem there — the razor-thin lunar crescent sets in early evening twilight.

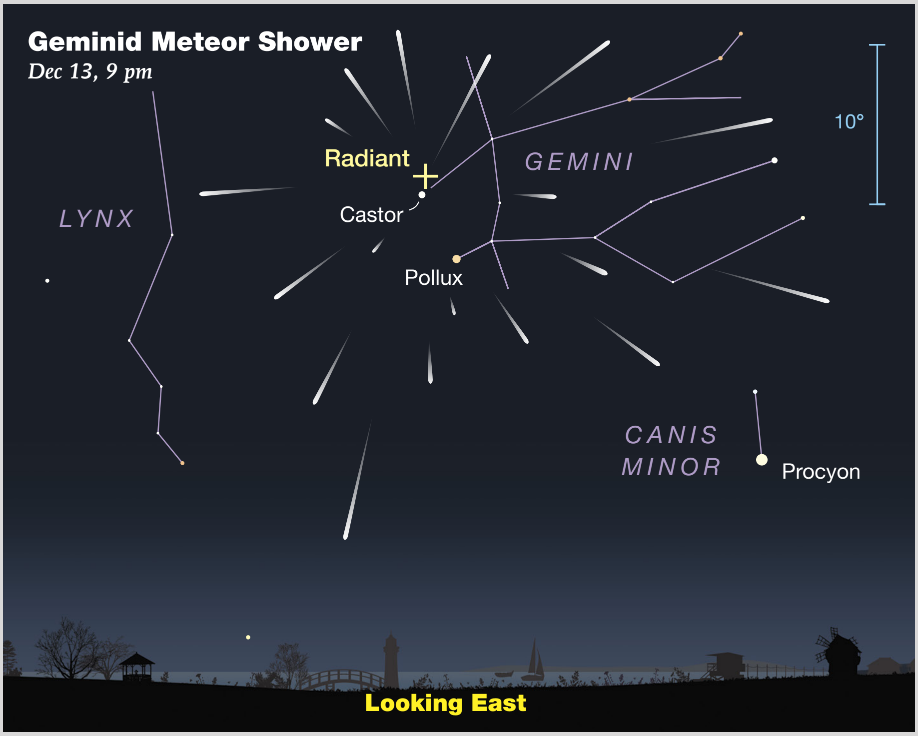
One of the shower's distinct advantages compared to other major displays is that the radiant, located near Castor in Gemini, stands nearly 30° high in the east-northeast by 9 p.m. local time. That means you can watch at least part of the display and still manage to get to bed at a decent hour. And by timing your meteor watch for the evening hours, you also avoid the chilliest temperatures a December night can produce, which typically occur in the hour or so before dawn.

However, the shower really is at its best in the predawn hours when the radiant is highest in the sky. For that reason, some meteor-watchers prefer to catch an after-dinner nap so they can begin their viewing session at midnight when activity starts to pick up. Not only does a vertiginous radiant mean fewer meteors get eclipsed by the horizon, but after midnight Earth faces *into* the direction of its orbital motion and meteoroids slam headlong into the atmosphere, increasing both their speed and number.

▲ More than 50 meteors, including a spectacular fireball, flare over the Xinglong Observatory in China's Hebei Province in this composite image captured by Steed Yu during the December 2015 Geminid meteor shower. The Geminids are one of the most reliable meteor showers and the richest with more than 100 meteors visible per hour at maximum from pristine skies.

If you want a Geminid warm-up, head out on the morning of December 12th when you might see a few slow-moving meteors from Comet 46P/Wirtanen. The so-called Wirtanen meteors reach their peak around 11:20 UT (6:20 a.m. EST) and appear to radiate from two different locations — one in southern Sculptor, some 4½° north of Alpha (α) Phoenicis, and another between Alpha Pegasi and Beta (β) Piscium.

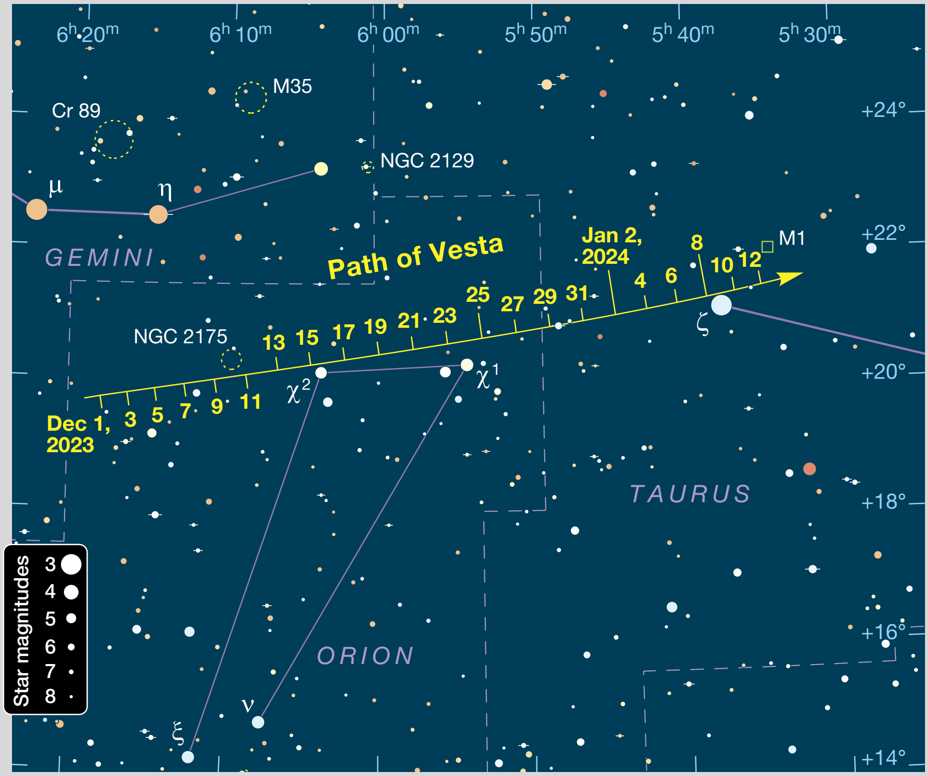
Bundle up and enjoy the show(s)!



Vesta Ambles Across Orion

IF YOU LIKE TAKING a celestial ride don't miss the Vesta train. The solar system's brightest and second-largest asteroid comes to opposition on December 21st, when it shines at magnitude 6.4.

While this year's isn't a particularly bright or close apparition, the asteroid will be easy to spot in binoculars and the most modest of telescopes. Vesta moves steadily westward in retrograde motion across northernmost Orion until the 28th, when it crosses into neighboring Taurus. On opposition night Vesta will be less than ½° north-northeast of 4.4-magnitude Chi^1 (χ^1) Orionis, one of the stars in the Hunter's upraised club. As it drifts westward, the asteroid passes north of 3rd-magnitude Zeta (ζ) Tauri on the nights of January 7th and 8th, and sits about ½° south of the famed Crab Nebula, M1, from January 11th to 13th.



Vesta's high northern declination makes it a tempting target for testing your visual acuity and your sky's naked-eye limiting magnitude. Pick a moonless night when the asteroid forms a simple and easily recognizable pattern with nearby field stars, as it does on the 23rd. Allow at least half an hour for your eyes to dark-adapt, then use averted vision to sight Vesta.

An Asteroid Eclipses Betelgeuse

A REMARKABLE OCCULTATION will take place on December 11–12 when the 14th-magnitude main-belt asteroid 319 Leona passes directly in front of Betelgeuse (Alpha Orionis) and hides it for several seconds.

At the time of writing there are slight uncertainties in the ground path and times, though astronomers will be carefully observing additional Leona occultations in the meantime to nail down the details. For the latest update, visit the International Occultation Timing Association's (IOTA) page at **https://is.gd/leona2023**.

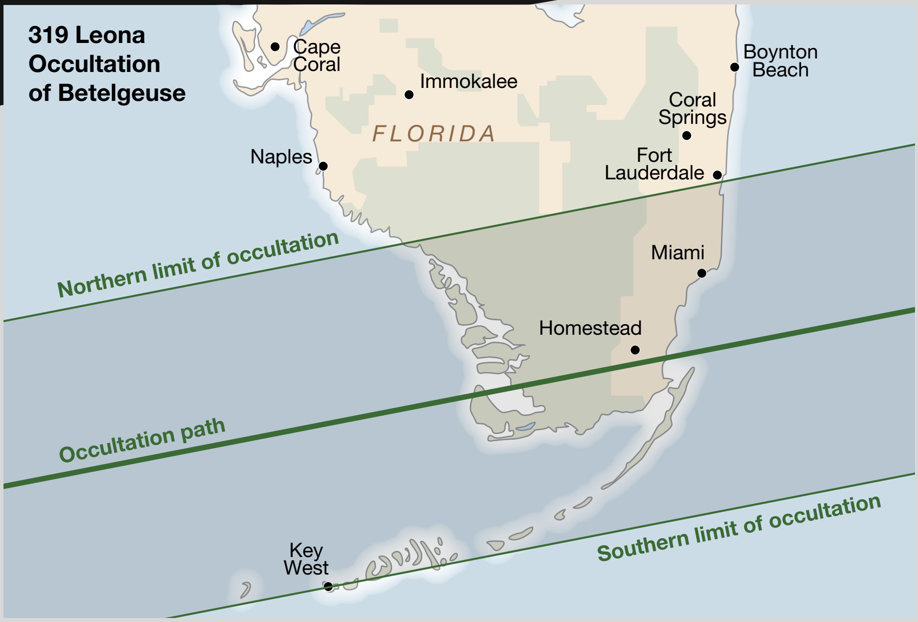
Both Leona and Betelgeuse have apparent diameters of around 50 milliarcseconds, but due to the uncertainties in Leona's size — which could be anywhere from 50 to 81 kilometers (31 to 50 miles) in diameter — the brightness drop could be as little as 0.5 magnitude all the way up to near-extinction.

The most likely scenario is an annular-style eclipse with Betelgeuse quickly dimming, reaching a momentary minimum, and then returning to its normal brightness. Along the path's centerline, the occultation could last nearly 12 seconds. In locations where Leona partially eclipses Betelgeuse, the event will be shorter and have less dimming.

Southernmost Florida is the only place in the U.S. where the occultation is visible. The centerline passes over Everglades National Park and just south of Homestead, where the occultation takes place around 8:25 p.m. EST on December 11th with Betelgeuse some 24° above the eastern horizon. The partial-eclipse zone extends north to include Miami and south to the Florida Keys. The event will also be visible from parts of eastern Mexico, southern Europe, Turkey, and central Asia.

Leona is a coal-black asteroid that resides in the outer realm of the main belt. Initial observations seemed to indicate an 18-day rotation rate, but recent data suggest a much shorter period of just 18 hours. This discrepancy is one reason we don't know the object's true size. A further complication arises because the size and shape of Betelgeuse is variable, affected by massive convective cells that burp blobs of the star's atmosphere into space, changing its apparent size and shape. Hubble Space Telescope images reveal that the star is decidedly non-spherical.

If it turns out Leona's apparent size equals or exceeds that of Betelgeuse, the occultation will be a dramatic sight anyone in the occultation path with clear skies can view with the naked eye.



▲ The occultation centerline cuts across southern Florida just south of Homestead, where the event takes place at around 8:25 p.m. EST on December 11th.

If the asteroid is smaller than the star, the event could be difficult to perceive. Hopefully by the time you read this, these uncertainties will be resolved.

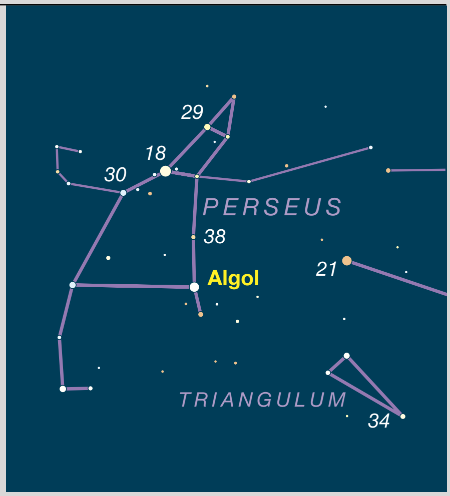
You can contribute scientifically useful observations by making an accurately timed video recording of the occultation. Join the campaign by filling out a form at **https://is.gd/leonacampaign**. If you're unable to make it to the centerline, you might be able to watch the occultation online. If it's livestreamed we'll post links at **skyandtelescope.org**, so check often.

It's not often that an asteroid eclipses a star as bright as Betelgeuse, so you don't want to miss this opportunity if you can reach the occultation path. Of course, getting there is only half the battle — you'll still need clear skies!

Minima of Algol

Nov.	UT	Dec.	UT
2	2:12	3	15:11
4	23:01	6	12:00
7	19:50	9	8:49
10	16:39	12	5:38
13	13:28	15	2:27
16	10:17	17	23:17
19	7:06	20	20:06
22	3:55	23	16:55
25	0:44	26	13:44
27	21:33	29	10:33
30	18:22		

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.



▲ Perseus approaches the zenith on chilly December evenings. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

IF YOU'RE THE TYPE of observer who prefers using a telescope in the evening hours instead of after midnight, the best part of the current Jupiter apparition is now underway. The planet transits the meridian — where it's best placed for telescopic viewing — at the convenient hour of 9:30 p.m. local time on December 1st. By the end of the month, it hits that mark two hours earlier. In mid-December, Jupiter shines at magnitude –2.7 from southwestern Aries, where it presents a disk 46.2″ across. In effect, you can productively observe the planet from early in evening twilight until around 1 a.m.

Any scope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

November 1: 2:44, 12:40, 22:35; **2**: 8:31, 18:26; **3**: 4:22, 14:17; **4**: 0:13, 10:09, 20:04; **5**: 6:00, 15:55; **6**: 1:51, 11:47, 21:42; **7**: 7:38, 17:33; **8**: 3:29, 13:25, 23:20; **9**: 9:16, 19:11; **10**: 5:07, 15:02; **11**: 0:58, 10:54, 20:49; **12**: 6:45, 16:40; **13**: 2:36, 12:32, 22:27; **14**: 8:23, 18:18; **15**: 4:14, 14:10; **16**: 0:05, 10:01, 19:56; **17**: 5:52, 15:48; **18**: 1:43, 11:39, 21:35; **19**: 7:30, 17:26; **20**: 3:21, 13:17, 23:13; **21**: 9:08, 19:04; **22**: 4:59, 14:55; **23**: 0:51, 10:46, 20:42; **24**: 6:38, 16:33; **25**: 2:29, 12:24, 22:20; **26**: 8:16, 18:11; **27**: 4:07, 14:03, 23:58; **28**: 9:54, 19:49; **29**: 5:45, 15:41; **30**: 1:36, 11:32, 21:28

December 1: 7:27, 17:22; **2:** 3:18, 13:13, 23:09; **3:** 9:05, 19:00; **4:** 4:56, 14:52; **5:** 0:47, 10:43, 20:39; **6:** 6:34, 16:30; **7:** 2:26, 12:21, 22:17; **8:** 8:13, 18:08; **9:** 4:04, 14:00, 23:55; **10**: 9:51,

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19:47; **11**: 5:42, 15:38; **12**: 1:34, 11:29, 21:25; **13**: 7:21, 17:16; **14**: 3:12, 13:08, 23:03; **15**: 8:59, 18:55; **16**: 4:50, 14:46; **17**: 0:42, 10:37, 20:33; **18**: 6:29, 16:24; **19**: 2:20, 12:16, 22:12; **20**: 8:07, 18:03; **21**: 3:59, 13:54, 23:50; **22**: 9:46, 19:41; **23**: 5:37, 15:33; **24**: 1:29, 11:24, 21:20; **25**: 7:16, 17:11; **26**: 3:07, 13:03, 22:58; **27**: 8:54, 18:50; **28**: 4:46, 14:41; **29**: 0:37, 10:33, 20:28; **30**: 6:24, 16:20; **31**: 2:16, 12:11, 22:07

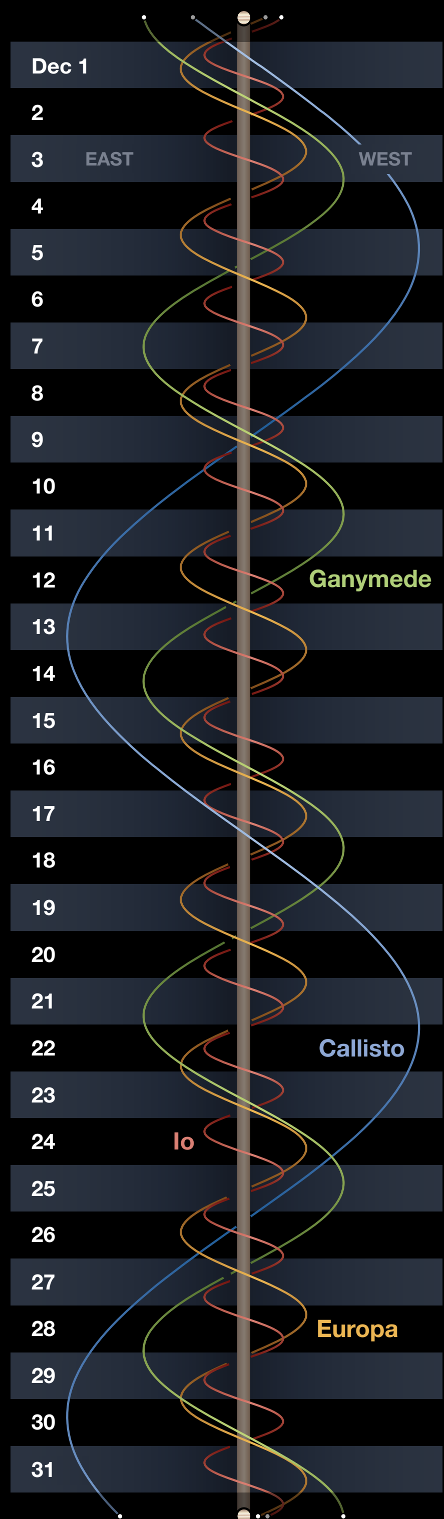
These times assume that the spot will be centered at System II longitude 48° on December 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 48° and 1²/₃ minutes later for each degree more than 48°.

Phenomena of Jupiter's Moons, December 2023

Dec. 1	16:27	I.Tr.I
	17:09	I.Sh.I
	18:36	I.Tr.E
	19:20	I.Sh.E
Dec. 2	3:18	III.Tr.I
	4:45	III.Tr.E
	6:08	III.Sh.I
	7:48	III.Sh.E
	10:13	II.Tr.I
	11:38	II.Sh.I
	12:28	II.Tr.E
	13:43	I.Oc.D
	13:57	II.Sh.E
	16:37	I.Ec.R
Dec. 3	10:53	I.Tr.I
	11:38	I.Sh.I
	13:03	I.Tr.E
	13:48	I.Sh.E
Dec. 4	4:31	II.Oc.D
	8:10	I.Oc.D
	8:25	II.Ec.R
	11:06	I.Ec.R
Dec. 5	5:20	I.Tr.I
	6:07	I.Sh.I
	7:29	I.Tr.E
	8:17	I.Sh.E
	16:48	III.Oc.D
	18:20	III.Oc.R
	19:58	III.Ec.D
	21:40	III.Ec.R
	23:22	II.Tr.I
Dec. 6	0:55	II.Sh.I
	1:38	II.Tr.E
	2:36	I.Oc.D
	3:14	II.Sh.E
	5:34	I.Ec.R
	23:47	I.Tr.I
Dec. 7	0:36	I.Sh.I
	1:56	I.Tr.E
	2:46	I.Sh.E
	17:41	II.Oc.D
	21:03	I.Oc.D
	21:44	II.Ec.R
Dec. 8	0:03	I.Ec.R
	18:14	I.Tr.I
	19:05	I.Sh.I
	20:23	I.Tr.E
	21:15	I.Sh.E
Dec. 9	6:41	III.Tr.I
	8:14	III.Tr.E
	10:10	III.Sh.I
	11:50	III.Sh.E
	12:31	II.Tr.I
	14:13	II.Sh.I
	14:47	II.Tr.E
	15:30	I.Oc.D
	16:32	II.Sh.E
	18:32	I.Ec.R
Dec. 10	12:41	I.Tr.I
	13:34	I.Sh.I
	14:50	I.Tr.E
	15:44	I.Sh.E
Dec. 11	6:52	II.Oc.D
	9:57	I.Oc.D
	11:04	II.Ec.R
	13:01	I.Ec.R
Dec. 12	7:08	I.Tr.I
	8:03	I.Sh.I
	9:17	I.Tr.E
	10:13	I.Sh.E
	20:13	III.Oc.D
	21:51	III.Oc.R
Dec. 13	0:00	III.Ec.D
	1:41	II.Tr.I
	1:41	III.Ec.R
	3:31	II.Sh.I
	3:58	II.Tr.E
	4:23	I.Oc.D
	5:50	II.Sh.E
	7:30	I.Ec.R
Dec. 14	1:35	I.Tr.I
	2:32	I.Sh.I
	3:44	I.Tr.E
	4:42	I.Sh.E
	20:03	II.Oc.D
	22:50	I.Oc.D
Dec. 15	0:23	II.Ec.R
	1:58	I.Ec.R
	20:02	I.Tr.I
	21:01	I.Sh.I
	22:11	I.Tr.E
	23:11	I.Sh.E
Dec. 16	10:09	III.Tr.I
	11:47	III.Tr.E
	14:12	III.Sh.I
	14:52	II.Tr.I
	15:51	III.Sh.E
	16:49	II.Sh.I
	17:09	II.Tr.E
	17:17	I.Oc.D
	19:08	II.Sh.E
	20:27	I.Ec.R
Dec. 17	14:29	I.Tr.I
	15:30	I.Sh.I
	16:38	I.Tr.E
	17:39	I.Sh.E
Dec. 18	9:15	II.Oc.D
	11:44	I.Oc.D
	13:43	II.Ec.R
	14:56	I.Ec.R
Dec. 19	8:56	I.Tr.I
	9:59	I.Sh.I
	11:06	I.Tr.E
	12:08	I.Sh.E
	23:44	III.Oc.D
Dec. 20	1:27	III.Oc.R
	4:02	III.Ec.D
	4:03	II.Tr.I
	5:43	III.Ec.R
	6:07	II.Sh.I
	6:11	I.Oc.D
	6:20	II.Tr.E
	8:26	II.Sh.E
	9:25	I.Ec.R
Dec. 21	3:24	I.Tr.I
	4:28	I.Sh.I
	5:33	I.Tr.E
	6:37	I.Sh.E
	22:28	II.Oc.D
Dec. 22	0:39	I.Oc.D
	3:02	II.Ec.R
	3:53	I.Ec.R
	21:51	I.Tr.I
	22:57	I.Sh.I
Dec. 23	0:01	I.Tr.E
	1:06	I.Sh.E
	13:42	III.Tr.I
	15:25	III.Tr.E
	17:14	II.Tr.I
	18:14	III.Sh.I
	19:06	I.Oc.D
	19:25	II.Sh.I
	19:32	II.Tr.E
	19:53	III.Sh.E
	21:43	II.Sh.E
	22:22	I.Ec.R
Dec. 24	16:18	I.Tr.I
	17:26	I.Sh.I
	18:28	I.Tr.E
	19:35	I.Sh.E
Dec. 25	11:41	II.Oc.D
	13:33	I.Oc.D
	16:22	II.Ec.R
	16:51	I.Ec.R
Dec. 26	10:46	I.Tr.I
	11:55	I.Sh.I
	12:56	I.Tr.E
	14:04	I.Sh.E
Dec. 27	3:20	III.Oc.D
	5:07	III.Oc.R
	6:27	II.Tr.I
	8:01	I.Oc.D
	8:03	III.Ec.D
	8:43	II.Sh.I
	8:45	II.Tr.E
	9:45	III.Ec.R
	11:01	II.Sh.E
	11:20	I.Ec.R
Dec. 28	5:14	I.Tr.I
	6:24	I.Sh.I
	7:23	I.Tr.E
	8:33	I.Sh.E
Dec. 29	0:55	II.Oc.D
	2:28	I.Oc.D
	3:16	II.Oc.R
	3:20	II.Ec.D
	5:41	II.Ec.R
	5:49	I.Ec.R
	23:42	I.Tr.I
Dec. 30	0:53	I.Sh.I
	1:51	I.Tr.E
	3:02	I.Sh.E
	17:22	III.Tr.I
	19:08	III.Tr.E
	19:40	II.Tr.I
	20:56	I.Oc.D
	21:58	II.Tr.E
	22:00	II.Sh.I
	22:17	III.Sh.I
	23:55	III.Sh.E
Dec. 31	0:18	I.Ec.R
	0:19	II.Sh.E
	18:09	I.Tr.I
	19:22	I.Sh.I
	20:19	I.Tr.E
	21:31	I.Sh.E

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

Observing the Moon Mappers

Track down the craters named after the giants of lunar cartography.

NASA / GSFC / ARIZONA STATE UNIVERSITY

The Moon was the first astronomical object to be studied scientifically. Even the first small telescopes revealed details never before imagined. Many observers soon began drawing maps to record the lunar surface. Those who drew the best-known ones were later commemorated with crater names. You can trace the development of lunar cartography by observing the craters honoring these early Moon mappers.

The best known (if not first) early, fairly accurate rendering of the lunar surface was by Galileo Galilei, whose watercolors are an artistic record of discovery in late 1609. With his 20× telescope, Galileo famously discovered hollows, mountains, deep valleys, and flat plains — showing the Moon was not an idealized perfect sphere but a world with varied terrains that reminded him of Earth. Despite his extraordinary discoveries, he was honored with an inconspicuous, 16-km-wide (10-mile-wide) crater (**Galilaei**) on the northwestern side of Oceanus Procellarum, close to the lunar limb.

The earliest map of the nearly complete visible lunar surface was made by the Flemish mapmaker Michael van Langren in 1645. He rushed his map and included the least amount of detail, naming craters after royalty and Christian saints as well as ancient philosophers and scientists. This was quickly followed by better maps made by the Polish astronomer Johannes Hevelius (1647) and Giovanni Riccioli of Italy (1651). Both Hevelius and Riccioli introduced their own systems of nomenclature. Hevelius undertook the first large scientific investigation of the Moon, *Selenographia*, which included descriptions of interesting features, eclipses, phase maps, and areas visible during good librations.

Riccioli published a two-volume book about astronomy that included the Moon and featured two maps drawn by a fellow Jesuit, Francesco Grimaldi. The nomenclature system introduced in the Grimaldi/Riccioli map continues to be the basis for naming features almost four centuries later.

All of these mid-17th century mappers are commemorated on the Moon. **Langrenus** is a prominent, 132-km crater at the eastern shore of Mare Fecunditatis — a crater named by van Langren for himself. **Hevelius** is a 114-km-wide, degraded version of Langrenus, located south of Galilaei. **Grimaldi** is the 235-km-wide, rimmed central mare of what we now recognize as the Grimaldi Basin, and immediately to its northwest is 146-km **Riccioli**.

German astronomer Tobias Mayer was the first to painstakingly measure the positions of craters and other

features, making his the most accurate map of the time. Mayer's 1749 chart was not published until 1775 by Georg Lichtenberg, who added a latitude and longitude grid. The flat-floored, 33-km-diameter crater **T. Mayer** is found at the western end of Montes Carpatus, while the 20-km crater **Lichtenberg** is northwest of the Aristarchus Plateau in northern Oceanus Procellarum.

Although he planned to make a map of the entire Moon, the German observer Johann Schröter ended up publishing two large volumes, *Selenographische Fragmente*, in 1791 and 1802 that took *selenology* — the scientific study of the Moon — in a new direction. Schröter made hundreds of drawings of particular features and regions of the Moon, discovering more details than ever before, including mare ridges and rilles, and coined the term "crater." The 35-km-wide crater **Schröter** is found between Copernicus and Ptolemaeus.

A high point of lunar mapping was the publication of four quadrant maps beginning in 1834 and a single volume, *Der Mond*, in 1837. The authors were Wilhelm Beer and Johann Mädler, but nearly all the work was accomplished by Mädler using Beer's observatory and 3.75-inch refractor. Mädler's map was the best created up to then. With it he refined and extended Riccioli's nomenclature. But more importantly, *Der Mond* was the first modern scientific study of the Moon with detailed descriptions of all named features, including the sizes of craters and mountains as well as theories of the origins of surface features. The 28-km-wide crater **Mädler** is just east of Theophilus, while the 10-km-pit **Beer** is found in Mare Imbrium, southwest of Archimedes.

Telescopic photography changed lunar cartography with two seminal works. The first was the *L'Atlas photographique de la Lune*, a selection of 80 large photographic prints taken with the Paris Observatory's 24-inch refractor. French astronomers Maurice Loewy and Pierre Puiseux produced their atlas between 1894 and 1908. The 22-km ghost crater **Loewy** and the ghost-like 25-km **Puiseux** are found in the northeast and southern extent of Mare Humorum, respectively.

Despite these advances, hand-drawn maps weren't rendered completely obsolete. The *Named Lunar Formations* map and its accompanying catalog by Mary Blagg and Karl Müller, published in 1935, resolved numerous conflicts, confusions, and double-naming of craters that had accumulated over the previous centuries. **Blagg** is a 5-km crater found in Sinus Medii; 24-km **Müller** is a much older and battered crater found just east of Ptolemaeus.

The second and possibly most influential photographic map was the *Photographic Lunar Atlas* compiled under the direction of Gerard Kuiper of the Lunar and Planetary laboratory in 1960. This atlas used the best photographs from several major observatories and included four different illumination angles for each of its 44 fields. **Kuiper** is a 7-km crater found in Mare Cognitum. His atlas was used to measure positions and diameters of craters for the *System of Lunar Craters* that I coauthored as an undergraduate student. The *System* was accepted as the 2nd official International Astronomical Union lunar map and catalog, though no crater was named for David Arthur, the project leader.

During the 1960s and into the 1970s, a totally different type of map was created by Eugene Shoemaker and his colleagues at the United States Geological Survey (USGS). *The Geologic Atlas of the Moon* was a series of 88 maps at 1:1 million scale depicting the stratigraphy of all lunar features, from the youngest to the most ancient. Of all lunar maps made previously, this series incorporates the most science, and just recently it was updated and combined into the *USGS Unified Global Geologic Map of the Moon* (see the August issue, p. 52). The 51-km crater **Shoemaker** is the most difficult crater named after a Moon mapper to observe. It's nearly at the lunar south pole, and only occasionally is its rim visible telescopically.

The most advanced and useful Moon map is the Lunar Reconnaissance Orbiter (LRO) QuickMap (**https://quickmap.lroc.asu.edu**). This excellent digital atlas uses LRO images that form a complete, high-resolution global mosaic. Other data sets — including the USGS maps — can be set to overlay the LRO images, enhancing the site's utility. Mark Robinson is the leader of the LRO team — fortunately there's no lunar crater named for him, since one needs to be dead three years before that honor can be bestowed, and Mark is still young!

■ Contributing Editor CHUCK WOOD spends lots of time on cloudy nights exploring the Moon with the LRO QuickMap website.

Winter Astrophotography

'Tis the season to brave the elements and capture some stunning images.

Winter can be the perfect season for budding astrophotographers. The easily recognizable constellation of Orion, along with Sirius, the brightest star in the night sky, are great targets for even the most modest camera gear. The season's bright stars add sparkle to nocturnal landscapes, while snow-capped mountains or frozen lakes offer enchanting foreground vistas. And if you're looking to try your hand at deep-sky photography, then M42, the Orion Nebula, is an ideal starting point.

The season's shorter days also mean longer nights and additional hours to capture images. Even if you can't stay up late, you can get some shots in thanks to the early sunsets and brief evening twilight. In fact, the nights are so long that they offer three seasons worth of objects. The early evening provides a review of the previous season, while the pre-dawn hours presents a showcase of what's ahead.

Of course, it's not all good news. Colder temperatures can be uncomfortable and pose some unique challenges when it comes to your camera gear.

Don't Dew It

Taking your camera outside on a cold winter night won't cause any problems . . . initially. However, as your gear cools to below the dew point, water vapor in the air will start to condense on the front element of your lens. Initially, the effects are quite subtle, showing up as a halo, or "blooming" around bright stars. Over time, as the condensation

WINTER WIDE-ANGLE The readily recognized constellation of Orion, along with Sirius, the brightest star in the night sky, feature prominently in this wide-angle photograph that includes the faint, hazy band of the winter Milky Way. The slightly blue color-balance used in this photo helps convey the feeling of a cold winter night.

gets thicker, dim stars will disappear and the overall image will become hazy, as though clouds were passing overhead. And it can get worse. If it's cold enough, you could end up with a layer of frost on your optics similar to what you would find on a car windshield.

To fix this, don't wipe (or scrape!) your lens. Instead, you have to *gradually* bring the temperature of your equipment back above the dew point. But don't make the common mistake of simply taking everything indoors — this only makes matters worse. The warm, moist air inside will instantly condense on all the cold surfaces of your camera and lens. A better approach is to seal your camera in a plastic bag while it's still outside. This way when you bring it indoors, the moisture condenses on the plastic bag instead of your gear. Once everything has warmed up a bit you can remove your camera from the bag and let it dry out completely.

As with many things, an ounce of prevention is worth a pound of cure. Using a lens hood lessens the rate at which your lens radiates away heat, which will in turn slow the process of dew formation. These accessories are critical on humid evenings. If your lens didn't come with one, you can purchase an aftermarket version or even make one yourself out of waterproof material.

Unfortunately, lens hoods don't completely prevent dewing — usually they just buy you a bit more time. To keep your lens from fogging up it needs to maintain a temperature slightly higher than the dew point. The simplest way to do this is to attach one of those little chemical hand-warmer packets to the underside of your lens with an elastic band. A better (though more costly) solution is an electrically powered dew heater. Some run off 12-volt DC power, while others use a USB connection. Typical devices consist of two parts: a controller plus one or more heating bands that strap (usually with Velcro) around the lens.

Keeping Chill

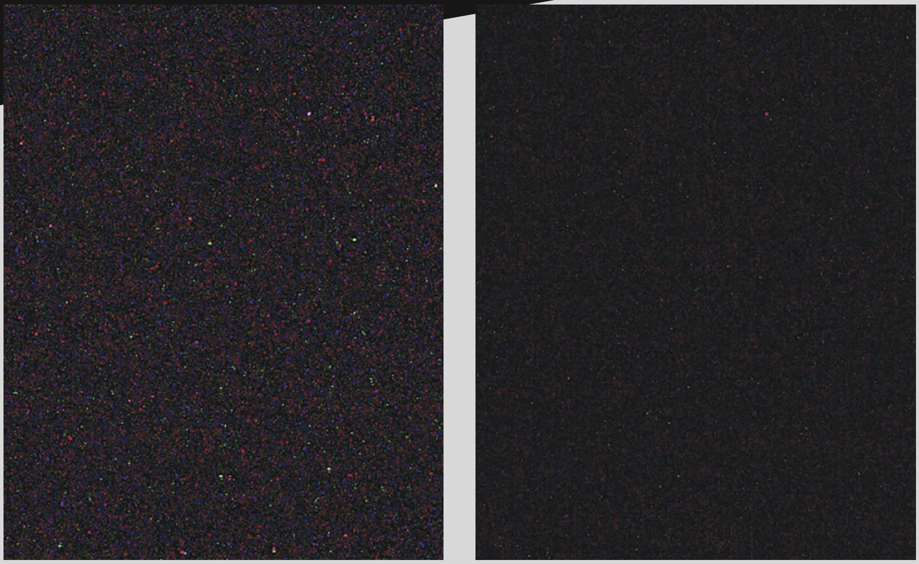
Cold weather can also affect the focus of your lens. As the temperature drops, the metal and plastic components in the lens barrel will contract slightly, throwing stars out of focus. My advice is to check your photos regularly during a winter imaging session. Just be careful not to breathe on your camera or lens when tweaking focus — the warm moist air you exhale will instantly condense on the glass.

◀ **FUZZY M42** Moist winter air and cold optics don't get along. Moisture condenses on any surface (including your lens) when temperatures fall below the dew point. The first signs can be quite subtle, with faint halos appearing around bright stars. As dew continues to form, dim stars won't be recorded, and the overall image becomes fuzzy and low-contrast. The effects of dewing are present in this two-minute exposure of the Orion Nebula, M42.

Camera batteries are impacted by cold conditions as well. It's worth keeping a spare one (or two) warm in your pocket or indoors while your camera is clicking away. Better yet, you can get a "dummy battery" adapter that allows you to power your camera directly from either an AC outlet or a portable power bank. These are essential accessories if you're planning to shoot a long, time-lapse sequence, a star-trail photo, or meteors. The adapters sold by camera manufacturers can be quite expensive, but you can usually find a low-cost alternative from a third-party source. Some of the newest mirrorless cameras even allow you to power them via a USB-C cable. Check your manual to see if this option is supported on your particular model.

Cold weather isn't all bad, however — digital cameras actually produce better images at lower temperatures. As imaging sensors heat up, thermal noise increases, creating a colorful, confetti-like pattern of speckles in long-exposure images. High-end, dedicated astro cameras have electronic coolers built in to minimize this effect, but you can

▲ **WIRELESS WONDER** The screen of an iPad dwarfs the rear display of this Canon 80D camera. Using Live View on a larger display makes obtaining perfect focus far easier, and because the connection is wireless, the iPad can be placed inside a warm car or house.



HOT MESS Digital-camera sensors work better in cool conditions, as illustrated by this pair of 60-second exposures taken with a Canon 60D DSLR camera working at ISO 3200. The cropped-in images show the difference in thermal noise when the sensor is running at 28°C (left) vs –5°C (right).

get similar benefits by shooting on cold winter evenings. A drop in temperature of as little as 6° to 8°C (10° to 15°F) cuts thermal noise in half, yielding cleaner-looking images that will withstand a lot of post-processing.

Cold Comfort

Taking photos on cold winter nights not only affects the equipment, but also the photographer. You'll need to dress more warmly than you would for normal daytime activities since you'll be standing still for long stretches. Extra layers of clothing are key to keeping you warm and comfortable. A Thermos of coffee or hot chocolate can also provide a welcome boost as you work with your camera to capture that perfect shot. Tuck a couple of hand warmers in your gloves to keep your fingertips from becoming numb. Most of all, remember it's important to stay warm since once you're cold, it's nearly impossible to shake off the chill without retreating indoors — something you'll be reluctant to do when you finally get one of those rare, crystal-clear, moonless winter nights.

Of course, you don't have to stand next to your camera at all. Several options allow you to stay inside while your camera clicks away out in the cold. Many models have a built-in intervalometer that you can program to take a sequence of exposures over a given time period. If yours doesn't have this feature, you can purchase an inexpensive external intervalometer. Some manufacturers even offer software that allows you to control your camera remotely, either via Wi-Fi or a USB cable. For example, Canon supplies a free computer program called *EOS Utility*, plus a mobile application called *Canon Camera Connect*, which runs wirelessly on iOS and Android devices.

A Wi-Fi connection allows you to control your camera from up to 10 meters (33 feet) away. This lets you sit inside in total comfort while your camera works away outside. And because the connection is wireless, there's no risk of shaking your camera while changing settings or firing the shutter.

Another advantage to connecting wirelessly is you can use the much larger screen of your computer or tablet to check for focus drift. Even better, if you have an auto-focus lens, many applications permit you to tweak the focus directly via your connected device. Having the ability to view a magnified image and make small adjustments remotely is a game-changer. Plus, being able to instantly review the images on your device's big screen allows you to confirm that you captured the keeper you were hoping for.

If this discussion has left you feeling a bit cool about winter imaging, there's one more option available. You can always take a vacation to some deserted tropical island and pack your astrophotography gear along with your suntan lotion and swimming trunks!

WINTER MOON On winter nights the full Moon follows a path similar to the Sun's on summer days. Rising well north of east, the Moon was perfectly placed over distant snow-capped mountains on a cold, clear evening when this shot was captured.

TONY PUERZER is a retired professional photographer and an avid amateur astrophotographer. He enjoys imaging on cold winter nights because there are no mosquitos to contend with.

IC 10 — The Hidden Dwarf

It may be small, but it's quite the treasure trove for owners of large telescopes.

◀ **LOCAL GEM** IC 10, a likely satellite of the Andromeda Galaxy, was the last member of the Local Group discovered visually. The image at left was obtained with the telescopes of Kitt Peak National Observatory in Arizona.

KPNO / NOIRLAB / NSF / AURA; DATA OBTAINED AND PROCESSED BY: P. MASSEY (LOWELL OBS.) / G. JACOBY, K. OLSEN, C. SMITH (NOAO / AURA / NSF); IMAGE PROCESSING: TRAVIS RECTOR (UNIVERSITY OF ALASKA ANCHORAGE) / MAHDI ZAMANI / DAVIDE DE MARTIN

It's been almost a decade since I first observed one of the largest, most massive star-forming regions in our Local Group of galaxies. The sight of it in my vintage 10-inch Schmidt-Cassegrain telescope (SCT) left me reeling. Despite what you might be thinking, I hadn't just observed the Great Orion Nebula. What I saw was more a feast for the imagination than the eyes, considering it lies 2,000 times farther and yet is at least 25 times larger.

I'm talking about NGC 604, a massive emission nebula in the Triangulum Galaxy (*S&T:* Nov. 2023, p. 58). Ever since that observation, I've been passionately (maybe even obsessively?) seeking every type of deep-sky object possible within galaxies outside our own (*S&T:* May 2021, p. 22). I mean, seeing a globular cluster in our Milky Way is nice . . . but I think seeing one in another galaxy is *beyond* marvelous. And that's where the obscure galaxy **IC 10** comes in.

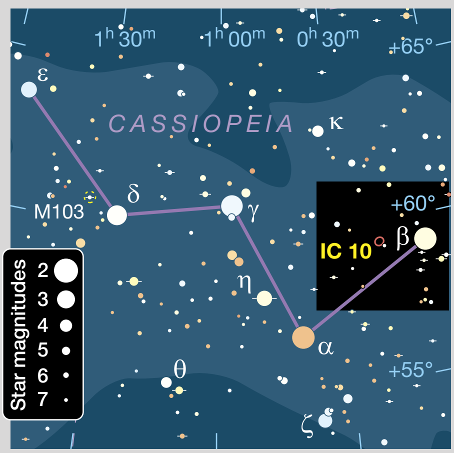
Swift's Galaxy

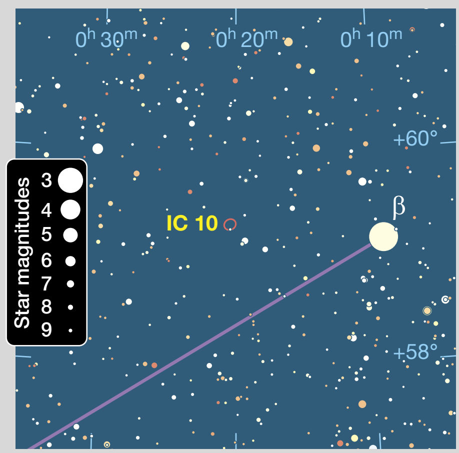
Comet hunter Lewis Swift first chanced upon IC 10, just 1.5° east of Beta (β) Cassiopeiae, in October 1887 while he was searching for new nebulae using a 16-inch Clark refractor from Rochester, New York. However, he published his finding a few months too late for John Louis Emil Dreyer to include it in the *New General Catalogue of Nebulae and Clusters of Stars*, published in 1888, and so this remarkable galaxy didn't receive an NGC designation. It garnered little attention until 1935, when Nicholas Mayall of Lick Observatory concluded it was "extra-galactic." He did so after studying several photographs taken using some of the largest telescopes of the day. However, substantial foreground extinction due to the object's location just 3.3° below the galactic plane made it difficult to classify any further.

The following year, Edwin Hubble published his seminal book *The Realm of the Nebulae*. In it, he called IC 10 "one of the most curious objects in the sky" and noted it might be a possible member of what he termed the "local group" of galaxies . . . if its distance could be determined. In 1941, Mayall obtained radial velocities through spectroscopy that not only proved IC 10 to be outside our own galaxy but that its two brightest "condensations" were not unlike emission nebulae.

A Mystery for the Ages

Owing to IC 10's location and appearance, Russian astronomers Grigory





▶ **EAST OF BETA CASSIOPEIAE** Look for tiny IC 10 at RA = $00^h 20.4^m$ and Dec = +59° 18′.

Shajn and Vera Gaze misclassified it as a nebula (Simeis 20) in their 1951 catalog listing. Meanwhile, Western astronomers puzzled over how to categorize IC 10 — many wondered if it wasn't a large, late-type spiral only a portion of which was visible through a "hole" in the galactic obscuration. Morton Roberts of Harvard College Observatory resolved this in 1962: Radio observations showed that neutral hydrogen (which is unaffected by galactic obscuration) aligned with the optically brightest part of the galaxy. Hence, no major portion of it was obscured, and Roberts confirmed that IC 10 was indeed an irregular galaxy.

Local at Long Last

With that mystery resolved, the question of IC 10's distance loomed large. In the early 1960s, astronomers knew little more than that it was fairly nearby, based on resolved features in images Fritz Zwicky obtained with the 200-inch Hale Telescope at Palomar Observatory. Over the next few decades, various measurements indicated that Hubble had indeed been prophetic in thinking it a member of the Local Group. Abhijit Saha (at the time at the Space Telescope Science Institute) and colleagues published an article in 1996 placing IC 10 securely in the Local Group by way of the Cepheid variables they'd discovered.

However, even today distance estimates vary wildly. This is due to IC 10's light not only undergoing strong extinction from gas and dust in our galaxy, but also from the intrinsic gas and dust in IC 10 itself! In fact, it has the most foreground extinction (about 3 magnitudes) of any of the Local Group galaxies.

Today, we understand IC 10 is not only an irregular galaxy but has ongoing star formation sparked by infalling gas from the aforementioned neutral hydrogen cloud. This fact was revealed primarily by the finding reported in 1992 of an unusually high number of extremely hot, blue stars known as *Wolf-Rayet stars* (*S&T:* Feb. 2023, p. 12). In fact, IC 10 has such energetic star formation that it's actually blue when we correct for foreground reddening — and it's the fifth most luminous member of the Local Group.

In 1972, just one year before he discovered his namesake comet that would go on to disappoint so many, Czech astronomer Luboš Kohoutek reported sweeping up IC 10 in a hydrogen-alpha survey while seeking new planetary nebulae. He detected the same two compact H II regions that Mayall had identified three decades earlier and cataloged them as **IC 10A** and **IC 10B**, plus a fainter one he designated **IC 10C**. Almost 20 years later, Paul Hodge and Myung Gyoon Lee (both then at the University of Washington) performed the most comprehensive survey of the galaxy's ionized hydrogen distribution and discovered 144 individual regions — an unusually high number for such a small galaxy. Their complex #111, which corresponds to Kohoutek's region IC 10A, was the brightest and most intriguing. But it wasn't until the Hubble Space Telescope imaged the galaxy in the late 1990s that we learned that at the heart of IC 10A lies a possible super star cluster of 17th magnitude.

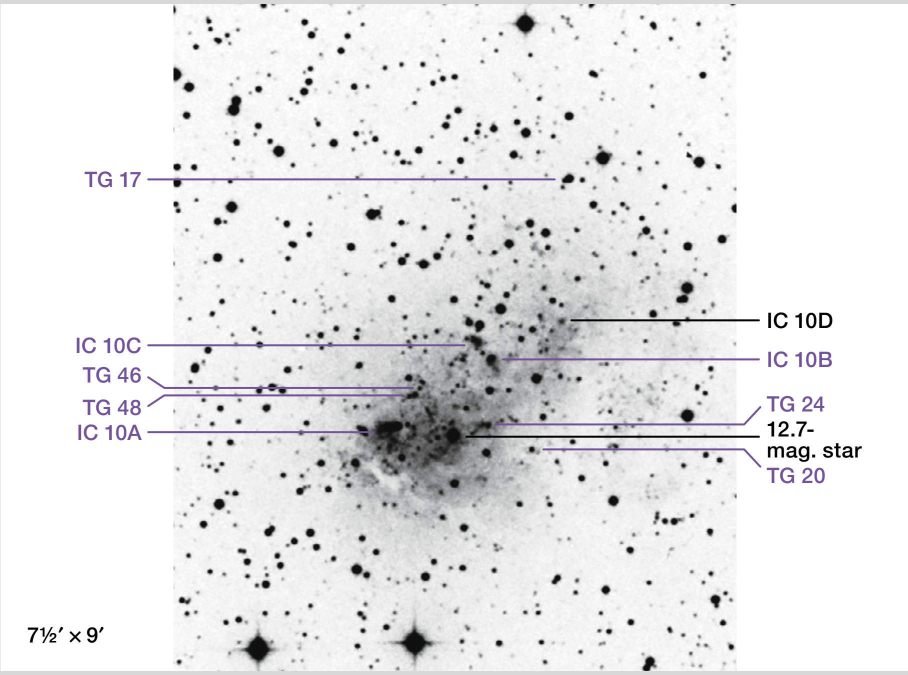
Russian astronomers identified seven star cluster candidates in the early 1990s with the 6-m Bolshoi Teleskop Azimutal'nyi in the Caucasus Mountains. But it was only in 2008 that they unveiled the vast majority of the 66 clusters we currently know of. In addition, IC 10 also counts some star clusters in its halo, with the farthest some 9.8′ out.

VIGOROUS STAR FORMATION This Hubble Space Telescope image highlights glowing gas clouds in green. Astronomers today refer to IC 10 as either a *starburst* or *blue compact dwarf* galaxy.

NASA / ESA / F. BAUER

Digging Deep

I haven't had a very long history with IC 10 considering my first observation was in 2015 with my 10-inch SCT. I was excited at the time to log my ninth member galaxy of the Local Group and was surprised by how bright it appeared. Since then, I've learned that Danish amateur Thomas Jensen managed an amazing sighting with his Zeiss 63-mm refractor at 34×! Using an eyepiece yielding 39× and boasting a 100° apparent field of view in my 6-inch f/5 reflector, I can detect the galaxy as a faint, ill-defined glow under my rural



◀ **CLUSTERS AND KNOTS** Use this guide to lead you to the various star clusters and H II regions that pepper the galaxy.

skies. If I didn't know exactly where to look, it would be essentially lost in the field of several hundred stars and 2.3-magnitude Beta Cassiopeiae riding the edge. Increasing the magnification to 56×, it's a soft, thumb-shaped glow just 3′ by 1.5′ with a 12.7-magnitude star in its lower half.

Nothing about this dwarf galaxy comes easy, what with the brightest H II star-forming region IC 10A being a challenge itself in my 10-inch SCT. At 300×, I've managed to see IC 10A 7″ east of a 14.5-magnitude star and glimpsed IC 10B lying 1.1′ north-northwest of the 12.7-magnitude star. In my 16-inch f/4.5 Dobsonian (which, coincidentally, has the same light-gathering capability as the telescope Swift used to discover IC 10), the galaxy is a faint, diffuse, oblong glow buried in a rich star field at 70×. At 150×, IC 10A shows enhancement when I add a narrowband filter. Upping the magnification to 440× and losing the filter reveals a small, round glow with no central brightening barely detached from the star 7″ away.

The H II knot IC 10B is also visible with averted vision at 440× as a small, nonstellar glow with a brighter center, while IC 10C, which lies 18″ farther northeast, isn't quite visible. At 600×, I found that the galaxy still easily fits in the 11′ field thanks to a 110° apparent-field-of-view eyepiece. Scrutinizing IC 10A, the edge opposite the 14.5-magnitude star appears soft and fans out. Using the motor-driven 36-inch Dobsonian at Whispering Pine Observatories in northwestern Arkansas, I was able to see a noticeable stellar core at 273×. This corresponds to TG 54, the 5.5-million-year-old star cluster that Deidre Hunter (Lowell Observatory) found using the HST. While not visible in my 16-inch even at 600×, I could glimpse IC 10C in the 36-inch at 273×. I couldn't detect knot D (my designation, at left) at all.

Clusters Ahoy!

Using the Whispering Pines 36-inch, I managed to see several of IC 10's star clusters one night in October 2022 when my Sky Quality Meter (lensed) reading near the zenith was 21.20. At 664×, the cluster that my eye found most easily was **TG 24**, which lies 30″ west-northwest of the 12.7-magnitude star. It barely beat out **TG 20**, though, some 40″ farther to the west-southwest. Swinging northward and well outside the galaxy's glow, I hunted down **TG 17**. To my surprise, with a lot of time and concentration, I was able to detect it even though a 15.0-magnitude star lies a mere 4″ northwest! Other clusters eluded me, except for the combined light of **TG 48** and **TG 46**, two 18th-magnitude objects.

If you choose to tackle this dwarf galaxy on a chilly night, take your time at the eyepiece and remember that its brightest star clusters should be within reach of a quality 24-inch telescope under dark skies.

■ **SCOTT HARRINGTON** is grateful to his friend Victor van Wulfen for digging up Kohoutek's paper.

Buried Treasures in IC 10

Object	Type	Mag(v)	Size	Age
IC 10	Galaxy	10.4	6.3′ × 5.1′	—
IC 10A	H II region	—	—	—
IC 10B	H II region	—	—	—
IC 10C	H II region	—	—	—
TG 24	Globular cluster	17.6	2.8″	4.8 Gyr
TG 20	Globular cluster	17.6	2.6″	4.6 Gyr
TG 17	Open cluster	17.3	1.5″	450 Myr
TG 48	Star cluster	18.0	0.9″	26 Myr
TG 46	Star cluster	18.4	1.0″	18 Myr

Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

I often tell people, "You don't truly own your telescope until you've drilled a hole in it." I can immediately tell the builders from the buyers, because the builders all nod and agree, whereas the people who just buy things from commercial vendors laugh nervously and edge away, often carrying their precious factory-built optics with them.

It's true, though: Ownership brings with it the opportunity to change the way something works — to customize it to match your wants and needs. It may seem a little scary to poke holes in something brand-new, but if those holes make it more useful to you, then why not?

In my monthly Astronomer's Workbench column I often describe specific modifications that people have made to improve the way their scope works, but in this article I want to talk about the concept behind them all. Why should you alter a scope that you paid good money for? Can you really improve on something that was designed by professional engineers?

Of course you can!

Without disparaging commercial telescope manufacturers, let me say that everyone has to make compromises between cost and quality, between form and function, between desire and reality. No design can be everything to everyone; that's why we have more than one telescope to choose from. And that's why you might find yourself contemplating a change to a scope that's close to but not exactly what you want.

Lefty or Righty?

Consider something as simple as which side of a Dobsonian you prefer to view from. People argue about the merits of pushing a Dob away from you as you track objects in the sky versus pulling it toward you, but there's no right or wrong way. It's a personal choice. Some like it lefty, some like it righty. But suppose you got a great deal on a scope, only it's rigged for pushing and you're more of a puller. What can you do?

You can move the focuser to the other side of the tube. On some scopes that's as easy as rotating the tube 180° when you set it in the rocker box. But even if you can't do that — if your altitude bearings are semicircles, for instance, or if the focuser isn't perpendicular to the side bearings — you can still move the focuser itself. Yeah, that means cutting a big ol' hole on the other side of the tube, plus drilling holes for the mounting screws. You also have to swivel the secondary mirror around and cover the hole where the focuser used to be. So what? It's a simple modification. You know exactly where to drill the holes and how big to make them, because the manufacturer already did that for you on the original side. And here's a little secret: If you're off a little, you can fudge it into place by elongating the mount holes, shimming the focuser, or even shifting the secondary up or down the optical axis.

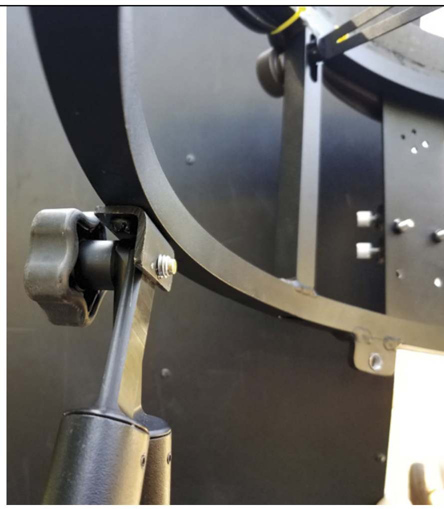
This modification isn't restricted to solid optical tube assemblies (OTAs), either. In fact, it's often even easier with a truss-tube scope. You can usually just re-mount the secondary cage 90° or 180° around without modifying anything. Your focuser will be upside-down, but it'll still work. If that bothers you, you can turn it around, using the exact same mounting holes as before. No drilling required. Some focusers are even rotatable within their mounts, so check for that first before you go to more trouble than necessary.

Flipping the OTA or the secondary cage means your finder will wind up underneath rather than on top. So, unless you want to crawl under your scope to aim it, you'll have to remount the finder. Big whoop. It's easy: Drill two more holes.

Righting Wrongs

One of my astronomy-club members, Dan Beacham, bought a 20-inch f/3.6 ultra-compact Dob in the hope that he wouldn't need a ladder for observing, but the focuser was

NOT QUITE LADDER-FREE Dan Beacham's scope came from the manufacturer with the focuser at an awkward angle.



▲ **TURN THE CAGE** Rotating the secondary cage on a truss Dob is simple. You might have to make new mounting brackets, but that's what angle iron is for. Note the original factory mounting point farther back to the right.

ALL BETTER With the focuser now aimed horizontally, Dan's scope is much easier to use.

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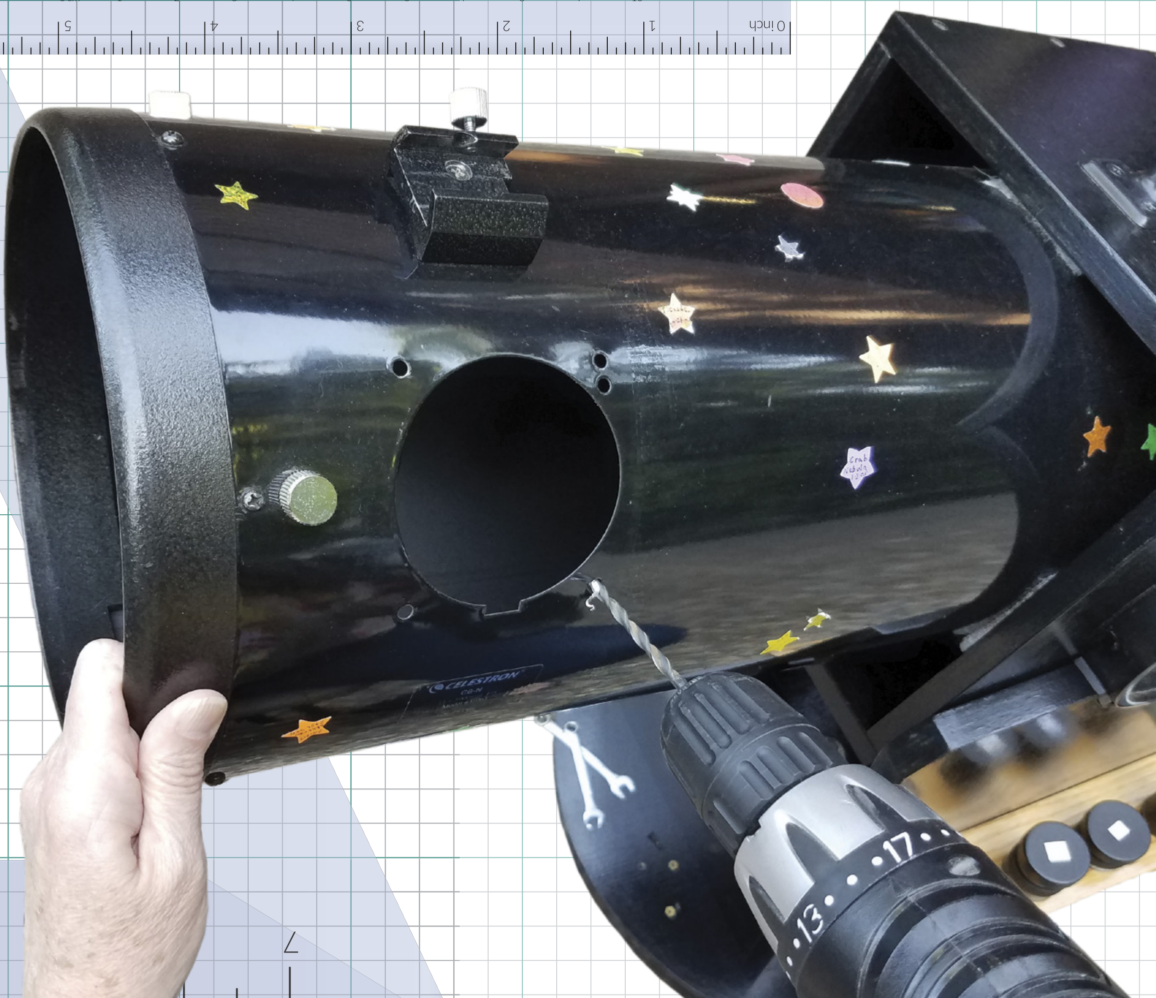
Modding Your Telescope

Take charge of your scope's design and make it perform better than ever.



ROOM FOR IMPROVEMENT
You don't truly own a telescope until you've drilled a hole in it. Note the extra hole drilled in the wrong location — it caused no harm.

placed at an awkward angle. It stuck upward at a 45° angle, which meant that when the scope wasn't aimed straight up, Dan had to get above it and look down. That largely negated the advantage of the scope's short focal length, so Dan and I rotated the cage so the focuser was horizontal. That meant fabricating new truss mounts, but that turned out to be easily accomplished with short sections of angle iron. We had to work up our courage to drill through the thin box tubing of the secondary cage ring, but we used small bolts and left plenty of metal for strength. And now Dan's focuser sticks out horizontally no matter where the scope is pointed, and he doesn't need a ladder.

◀ **NEEDS IMPROVEMENT** The collimation adjustment screws on this scope are crying out for a set of Bob's Knobs. You shouldn't need both a Phillips screwdriver and a hex wrench to collimate your mirrors.

Dan's scope required several additional modifications — as he says, "Many of them involving Loctite." One memorable night as he was setting up after a long drive over washboardy gravel roads, his scope's secondary mirror simply fell off in his hand as he was collimating it. The set screws holding it in place had all rattled loose! Several other bolts on the scope had also loosened up, so he fixed them all in place with thread-locking adhesive.

The rivets on Dan's telescope mirror box scraped against the side struts of the rocker box, so he put plastic skid plates in place to keep them from hitting. The altitude-bearing surfaces also needed to be replaced with Teflon in order to equalize the force required to move the scope in altitude and azimuth.

Sometimes it's the other way around, and the scope is stiffer in azimuth than altitude. Fortunately, that's an easy fix. First try loosening the nut on the pivot bolt that holds the rocker box to the ground board. If that doesn't fix it, then take the bolt out and put a stack of washers between the two boards. The washers will take some of the telescope's weight, reducing the load on the Teflon pads out near the perimeter, and the scope will move more freely. You'll have to experiment with the number and thickness of the washers until you get just the right feel, but you can fine-tune until the effort to move the scope in azimuth matches the effort to move it in altitude.

Eliminating Tools

Often a scope that's designed to be assembled and disassembled on-site will come with small bolts that require wrenches. You can make setup and tear-down much easier by using larger bolts with more easily gripped heads. My fix is to get a longer bolt, spin a couple of extra nuts up against the bolt head, and cover the nuts with a length of rubber hose (available at just about any hardware store). That lets me tighten and loosen them with just my fingers — no tools required.

There's a company called Bob's Knobs (**bobsknobs.com**), started in 1999 by Bob Morrow, that sells replacement knobs for the collimation screws in Schmidt-Cassegrain telescopes. It's the same concept: With Bob's Knobs you can use your fingers, rather than a hex wrench or a screwdriver, to make the fine adjustments required for collimation. This modification isn't just for Schmidt-Cassegrains, either: You can also replace the collimation screws on the back of Newtonian scopes. Bob has since branched out with custom knobs for many other applications, so check his website for ideas as well as materials.

▲ **SMOOTH TRACKING** Teflon altitude bearings made the scope move much more smoothly.

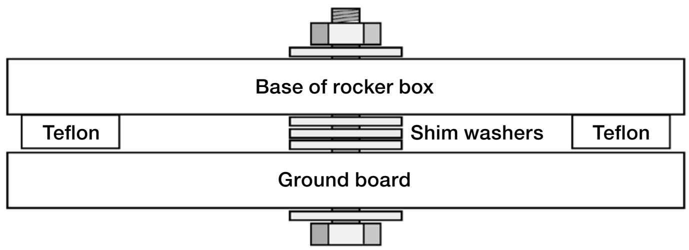
▲ **SCRAPE GUIDE** Skid plates keep mirror-box rivets from banging into rocker-box struts.

Speaking of collimating, how about installing a couple of thin plastic washers under the collimation screws on your secondary-mirror holder so it's easier to rotate it without loosening the center bolt? That lets you twist, rather than tilt, the mirror for side-to-side collimation, which is less likely to lead to vignetting. Cutting washers from a milk jug works great for this.

Back to the subject of knobs, consider installing a handhold on the front of your Dobsonian so you can nudge it along with the knob rather than with your hand on the lip of the scope and your fingers in the light path. Cabinet knobs and doorknobs work well for this, or you can go whole hog and make a form-fitting hand grip. This is a modification that seems trivial, but it makes using the scope so much more comfortable you'll wonder how you ever observed without it.

Another how-did-I-ever-do-without-it modification is a laser finder. Mount a green laser pointer so it's parallel to the optical axis of the telescope, and you'll never have to bend sideways or crouch down to look through a finder again. Just push the laser button and aim the beam at your target. My back used to hurt after a night of contorting to see through my optical finder, but a laser finder solved that completely. But be sure to check to see if there are any laws in your area regulating the use of green lasers before committing to this mod.

That leads directly to the next mod: Install dovetail brackets on each of your scopes so you can use the same laser finder on all of them. You can leave your other finders in place if you want. Optical finders still come in handy for star-hopping when you get near your target, or when your observing group includes any astrophotographers who won't appreciate your laser's beam intruding into their images.



▲ **AZIMUTH IMPROVEMENT** Washers stacked between the rocker box and ground board can help to reduce friction in the azimuth axis.

Flocking, Fans, and Other Mods

Focusers often have shiny metal knobs, which can reflect unwanted light into your eyes when you lean in for a look. Other metal screws and various other parts might do the same. A black Sharpie is your friend here. Darken those screws, knobs, etc. so they don't disturb your view through the eyepiece. If your scope has a white tube, paint the top half black. You'll be surprised at how much difference that makes, especially if you observe with both eyes open (as many of us do to prevent squinting).

Even the flat black inner surface of a telescope tube can reflect light. Flocking the inside of the tube can improve contrast considerably. (Flocked paper is an adhesive-backed, velvety fabric with millions of tiny, black, light-absorbing fibers sticking out of it.) I didn't realize how much difference flocking makes until I was observing with Lauren Wingert (*S&T:* Aug. 2023, p. 74), who had flocked the inside of her 10-inch Dob. I had my open-truss trackball of equal aperture, but the view through Lauren's scope was vastly more contrasty than in mine. I flocked the inside of my secondary cage and added a shroud, and the next time we observed together my view matched hers.

Speaking of shrouds: Yes. They're well worth the effort. They cut down on stray light and also help prevent dew from settling on your primary and secondary mirrors.

▲ **GRIPPING CONVENIENCE** A hand knob helps you move the telescope smoothly. Yes, that's a doorknob. They're *made* for hands.

▲ **LASER-GUIDED** A green laser pointer makes a dandy finder. See my column on making the mount in the March 2022 issue, page 72.

Then there are active dew heaters. In some climates, they're not just a good idea; they're essential. These are little battery-powered heating pads or strips that attach to the secondary, to eyepieces, to finders, etc. I've even seen dew heaters on primary mirrors, which seems counterintuitive when most people run fans to cool their mirrors instead, but let me ask you this: Would you rather observe with a slightly distorted but dry mirror, or would you prefer to pack up and go home early when the mirror dews up? Uh-huh. Don't be afraid to heat the primary if yours dews up regularly.

◀ **COOLING ASSIST** Installing a fan can be as simple as hooking rubber bands to your collimation bolts.

I mentioned fans. They're standard on some scopes, but if your scope isn't so equipped, you might want to add one. Blowing air on the back of the mirror at the start of a night will help it reach ambient air temperature and help keep it there. And adding a fan is simple. You can wire it in place or even just rubber-band it to the collimation bolts on the back of the scope (those knobs you installed to replace the hex-head or Phillips-head screws, right?). Celestron offers an inexpensive, USB-powered cooling fan that is easy to adapt to most any mirror cell (**https://is.gd/coolingfan**).

When you install your fan, you might have to remove the blocking plate that some manufacturers include on the rear of the mirror cell. You should remove that anyway, just to give your mirror direct exposure to air for cooling even without a fan. Yes, that exposes the mirror to more dust, so buy a shower cap and put it over the bottom of the scope when you aren't using it.

There's always the addition of an eyepiece rack. Don't forget to shield it from dew with the modification I featured in my column a year ago (*S&T:* Dec. 2022, p. 72).

If you have any heavy eyepieces or Barlows, you may need to add a counterweight to the back of the scope to compensate. Easy-peasy! Find a convenient spot for it, stick a strip of Velcro there, attach the matching Velcro to your weight, and slap it on. Use a long strip along the optical axis so you can adjust the balance for various eyepieces by moving the weight up and down the tube. If you've got a metal tube, you can forego the Velcro and use a magnet to hold the weight in place.

Yours to Improve

I could mention dozens more modifications, but you get the idea. Optimizing your scope is a time-honored tradition among amateur astronomers, and people are coming up with new ideas all the time. The next innovation might be yours.

If you think modifications are only for sub-standard scopes, think again. Even top-end scopes can stand some customization. As Dan Beacham points out, "The biggest modifications I've done have been on my most expensive telescope."

That said, be aware that making changes could void your warranty. If you do something irrevocable, make sure it's right. But don't be afraid to do it if you know it's right. Because it's your telescope to use and to improve.

Or it will be, once you've drilled that first hole in it.

■ Contributing Editor **JERRY OLTION** considers every new telescope a blank canvas.

▲ **EXTRA-DARK TUBE** Flocked paper is way darker than flat black paint. That means significantly greater contrast at the eyepiece.

▲ **EASY COUNTERWEIGHT** Counterweights don't have to be pretty. If necessary, you can use a convenient rock.

Up Close and Personal

UNDER ALIEN S IES: *A Sightseer's Guide to the Universe*

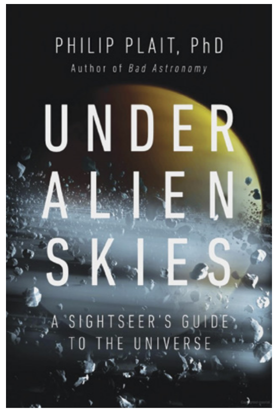
Philip Plait, PhD
W. W. Norton & Co., 2023
336 pages, ISBN 978-0-393-86730-5
US$30.00, hardcover

PHIL PLAIT, well-known author of the blog, newsletter, and book *Bad Astronomy*, has wondered since he was a kid what celestial objects would look like up close. What if you were nearby in a spaceship or — if the object had a solid surface — standing on it? After he earned his PhD in the 1990s and began giving public talks on astronomy, he found that many others had the same question. So he wrote this book.

The Moon

Plait starts with our nearest neighbor. The Apollo landings gave us Earthlings some notion of what it's like to be on the lunar surface, but Plait seasons our understanding. He reminds us that even when the Sun blazes at midday, the sky would remain black, because there's little atmosphere to light up the sky. When the Sun sets, the light disappears instantly. "Just *bang*, night," he writes. And we'd have to contend with the temperature change, which can swing from 250°F at noon to –200°F before dawn.

Thanks again to Apollo, we've seen Earth from the Moon. But have we considered how bright earthshine would be on our satellite? As Plait observes, Earth is about 14 times bigger and three times more reflective than the Moon, so reading by Earthlight when our planet is "full" would be a cinch. And how about watching a total solar eclipse from the Moon? Earth would be much larger in the sky than the Sun, so you wouldn't see as much of the solar corona during totality. "That's okay," Plait writes, "because this eclipse has something no Earth-bound stargazer could ever see: a world *with an atmosphere* blocking the Sun."



Saturn

Plait then shuttles you to Mars and the asteroids before heading out to Saturn. The Cassini mission gave us breathtaking closeups of the rings, but Plait takes you even closer. If you were in a spacecraft right at the outer edge of the outermost ring, he says, that edge wouldn't appear curved when you looked along it but perfectly straight. "The rings are circles, but they're circles *170,000 miles across*," he writes (he likes emphasis). They're also incredibly thin — in most spots, only 40 feet thick.

If your hypothetical spaceship arrived at that outer rim edge-on to Saturn, the rim would appear as a one-dimensional line in the sky. But rise just up over that rim and you'd see a vast plain of icy boulders stretching towards the gas giant. "Perspective plays havoc with your eyes and brain," Plait writes, noting that the boulders shrink with distance toward Saturn, but the lack of air means they're just as sharp far away as nearby. Imagine if your ship flew into Saturn's shadow, with the Sun on the opposite side of the planet from you. The rings would fill the sky in a grand, whitish arc — except where the world's 75,000-mile-wide shadow erased them, leaving pure black.

Far-away Worlds

As an astronomer, Plait makes use of the latest scientific thinking, of course. But since we have no close-up images of deep-sky objects, he has no choice but to speculate on near views of objects beyond our solar system. Readers will have to judge for themselves how successful he is.

Plait steers us to the TRAPPIST-1 system of exoplanets, to planetary nebulae, and to star-forming regions like the Orion Nebula. He explains how someone on a planet orbiting two stars would enjoy "sunsrise" and "sunsset," and how traveling near a black hole would be "trippy to see, one of the weirdest sights in your life." And how about stargazing on a planet orbiting a star near the core of a globular cluster? After dark, Plait says, instead of the several thousand stars visible at a dark-sky site on Earth, you'd see tens of thousands of suns overhead, some of them so bright as to make you squint. On the surface around you, multiple shadows of different lengths would shoot out on every side.

It's a delightful prospect, but globulars formed so long ago, Plait notes, that it's possible they have no rocky planets at all. In providing such caveats, he enhances our trust in him as our guide.

Altogether, Plait does a fine job taking you right up to wondrous objects. As he writes, "We may not know precisely what it's like to fall into a black hole or visit a star as it's forming, but our understanding of astronomy, physics, mathematics, and more can feed our minds, allowing us to imagine with great accuracy and remarkable detail what it would be like if we were there."

■ **PETER TYSON** wishes the galaxy-crossing spaceships Plait imagines were real and he had a seat on one.

The Poseidon-M PRO

How well does Player One Astronomy's first cooled, deep-sky camera perform?

◀ The Poseidon-M PRO package comes with everything shown here, including a 2-meter-long (6½-foot) USB 3.0 type-C cable, a ½-meter type-C to C cable for connecting the filter wheel or other accessories, and a type-C to type-B adapter cable. The package also includes two extension tubes, an M48-to-M42 (T) adapter, an air blower tool, hex wrench, replacement screws, and a T-to-1¼-inch nosepiece adapter.

ALL IMAGES COURTESY OF THE AUTHOR

Player One Astronomy Poseidon-M PRO

U.S. Price: $2,299

Phoenix Wheel 7 × 36mm: $299

Player-one-astronomy.com

What We Like

Low read and pattern noise

No amplifier glow

Fast USB 3.0 connection

What We Don't Like

Only one port to connect electronic accessories

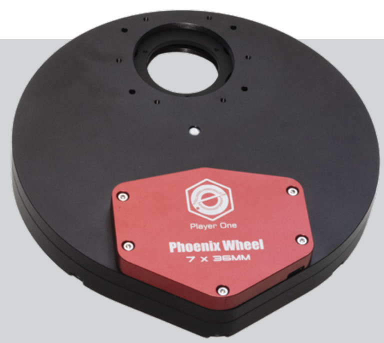
THERE ARE A LOT OF NEW astronomy cameras these days, particularly those featuring mid-sized detectors produced by Sony. Choosing an affordable model from a reputable manufacturer can be difficult. Player One Astronomy, a relatively new entry in the astrophotography camera market, has been attracting the attention of astrophotographers. The company, based in Suzhou, China, started out manufacturing small, USB 3.0 cameras intended for planetary imaging and autoguiding. We've tested a few of these (*S&T:* Feb. 2022, p. 66).

Recently, the company introduced the first model in its rapidly expanding series of cooled cameras aimed at deep-sky astrophotographers. The Poseidon PRO is a 26-megapixel CMOS camera using Sony's APS-C-format IMX571 sensor. Available in both monochrome and one-shot-color versions, we borrowed the monochrome Poseidon-M PRO along with a 7-position filter wheel to see if the company's deep-sky cameras match the quality of its other products.

First Impressions

The Sony IMX571 sensor at the heart of the Poseidon-M PRO is a 26-megapixel, APS-C-format detector containing an array of 6,252 × 4,176, 3.76-micron-square pixels that touts a quantum efficiency of 91%. It can operate in 8-bit mode (helpful for planetary imaging) and 16-bit mode, which is best for deep-sky photography. The camera and filter wheel arrived well-packed in a stylish box. The build quality of the camera is excellent. It has a red and black matte anodized finish and stainless-steel screws that won't rust with continual exposure to moisture.

The round plate on the front of the camera has M48 threads to connect to its accessories and includes four sets



▲ The Phoenix Wheel 7 × 36mm Electronic Filter Wheel is 20 mm thick and accepts 36-mm unmounted filters. The company also offers models that accept mounted filters as well as larger and smaller formats.

of tip/tilt screws used to adjust the planarity of the whole camera should the sensor be slightly tipped to the optical plane. These screws are conveniently located so that adjustments can be made without having to remove the camera from the telescope — a nice touch. The chip seemed accurately mounted in my unit, so I didn't have to make this adjustment.

In addition to the camera, several accessories are included to help get you started. Two extension tubes come with the camera — one that's 17.5 millimeters long and another that's 20 mm to achieve the proper spacing to any field flatteners, depending on if you're using the monochrome model with the Phoenix filter wheel (which is 20 mm thick) or the color version without the wheel. An internal M48-to-M42 adapter is also included to allow the use of T-thread accessories. (Handily, it doesn't add to the back focus distance.) The back focus, or the distance between the front threads of the camera and the image sensor, is 17.5 mm. The camera also comes with a 1¼-inch nosepiece adapter, cable ties, a blower bulb, three USB cables, and a rigid cloth camera case.

The camera connects to your computer via an included USB-C to USB-A adapter cable. In addition, the camera is equipped with a passthrough USB-C connector on the back (labeled "device"), where you connect the short USB-C cable directly to the Phoenix filter wheel. It seems odd that the camera only includes one accessory port, as most imagers would likely have an electronic focuser and autoguider that also requires a computer connection. Note that only the main camera connection operates at USB 3.0 speed.

One thing that really impressed me was just how fast image downloads occurred with the camera. While operating in 8-bit mode, I was able to get close to the advertised 15 frames per second on my MacBook Pro while operating the camera at full resolution. This is significantly faster than other cameras I've used having the same detector. The camera is capable of cooling to 40°C below ambient temperature, and the dark current is so low when cooled that I found I didn't need dark calibration frames. I was especially pleased with the absence of the dark pattern noise that had troubled CMOS sensors in the past.

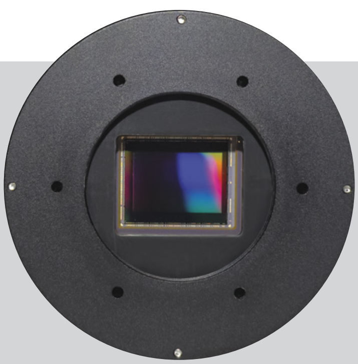
Assembly

Initially I was a bit confused when deciding how to orient the camera in my telescope focuser. The text on the sides of the camera is rotated 90° from the printing on the rear of the camera. Which way is up? I soon discovered the detector is mounted so that the widest dimension aligned with the logos on the side of the camera body and not the printing on the back.

▲ Installing the Phoenix Wheel to the Poseidon-M PRO requires disassembling the tip/tilt plate on the camera and connecting its front plate to the filter wheel with the six included hex screws. The camera is then reconnected to the front plate.

The optional Phoenix Wheel has spaces for seven 36-mm unmounted filters (not included). I used my set of Chroma LRGB and narrowband filters, which are secured with gaskets and retaining rings. The filter wheel uses a Hall effect sensor for accurate, repeatable filter positioning. The device's hybrid stepping motor is smooth and quiet when in operation. Notably, the wheel rotates in both directions, so the wheel always takes the shortest route to put the chosen filter inline.

You'll need to remove the front half of the camera's tip/tilt plate to connect the Phoenix filter wheel. That part is screwed directly to the back of the filter wheel, and then the camera is reattached to its front plate. The connection is very secure and places the camera flush to the filter wheel, so no addi-



▲ The camera's 23.5 × 15.7-mm, APS-C-format detector sits 17.5 mm from the front surface of the tip/tilt adjustment plate. The six holes are for connecting the filter wheel or other accessory.

▲ The rear of the camera body has three inputs — a USB-C port labeled DEVICE that connects to accessories, another USB-C port that connects to your computer (labeled MAIN), and a 5.5 × 2.1-mm DC input jack used to power its dual-stage thermoelectric cooling.

▲ Users need to remove the front plate of the Phoenix Wheel to install the filters. The camera lacks a mechanical shutter, so you'll have to cover the front of the telescope in order to record dark calibration frames.

◀ *Clockwise from lower left:* This image of the Leo Triplet (NGC 3628, M65, and M66) was captured with the Poseidon-M PRO from the author's suburban yard in Florida. The photo combines nearly 10 hours of 1-minute exposures shot through LRGB filters.

tional back-focus space is taken up.

When connected to the Poseidon, the detector sits exactly 37.5 mm from the front of the filter wheel. There are 6 additional threaded holes on its face where Player One's off-axis guider would connect (not included in this review). I used the 17.5-mm spacer from the camera to extend the back focus to 55 mm. That typically places the detector at the correct distance to use with most field flatteners, reducers, and camera lenses (with a proper adapter).

Power is supplied to the Poseidon through its USB-C connection to your computer. There's a DC input socket on the rear of the camera body, though it only provides electricity to the thermoelectric cooler. Player One doesn't provide a power cable, though the company recommends a 3-amp, center-positive cable. Most of the time I powered the cooling with a 12-volt, deep-cycle battery or a solar battery. One night the power cable accidentally came out because I didn't tie it down properly, yet the camera never faltered. Fortunately, I was sitting next to the scope at the time and heard something drop in the dark. I noticed the temperature on the camera start to rise and realized what had happened. After plugging the cooler's cable back in, the temperature quickly returned to its set point without me having to reset the camera.

This minor accident made me realize that I can use the Poseidon-M PRO even without cooling, just like any planetary camera. I took advantage of its large chip and fast frame rate to image the Sun's full disk in white light, collecting a few hundred images very quickly and combining the best into the result seen on the facing page. No mosaicking was needed, as would be necessary with the smaller detectors typically found in dedicated planetary cameras.

▲ This portrait of Sh2-308 consists of 2 hours total exposure through a narrowband O-III filter using 5-minute sub-exposures as well as 10 minutes per color channel. It was recorded with the author's 150-mm Sky-Watcher Esprit 150 refractor from the Florida Keys.

Under the Stars

I tested the Poseidon-M PRO for several months paired with multiple telescopes. Most of the time I controlled the camera using Software Bisque's *TheSky Imaging Edition* on a Mac with the help of a plug-in for Player One Astronomy cameras available from RTI-Zone (**rti-zone.org**). The camera is ASCOM-compatible, so other ASCOM-compliant software shouldn't have any issues controlling it. Additionally, I operated the camera using *SharpCap Pro* on a PC running Windows 10.

In use, the camera worked flawlessly. Not once did it ever lock up or deliver a corrupted image. This is due in no small part to the onboard, 512-megabyte DDR3 memory operating as an image buffer. With high-speed applications, this buffer ensures that no frames are lost even if your computer can't write all of them to its hard drive as fast as they download. And even with long-exposure work, reading the sensor into a buffer

rather than immediately transferring it over USB prevents image corruption.

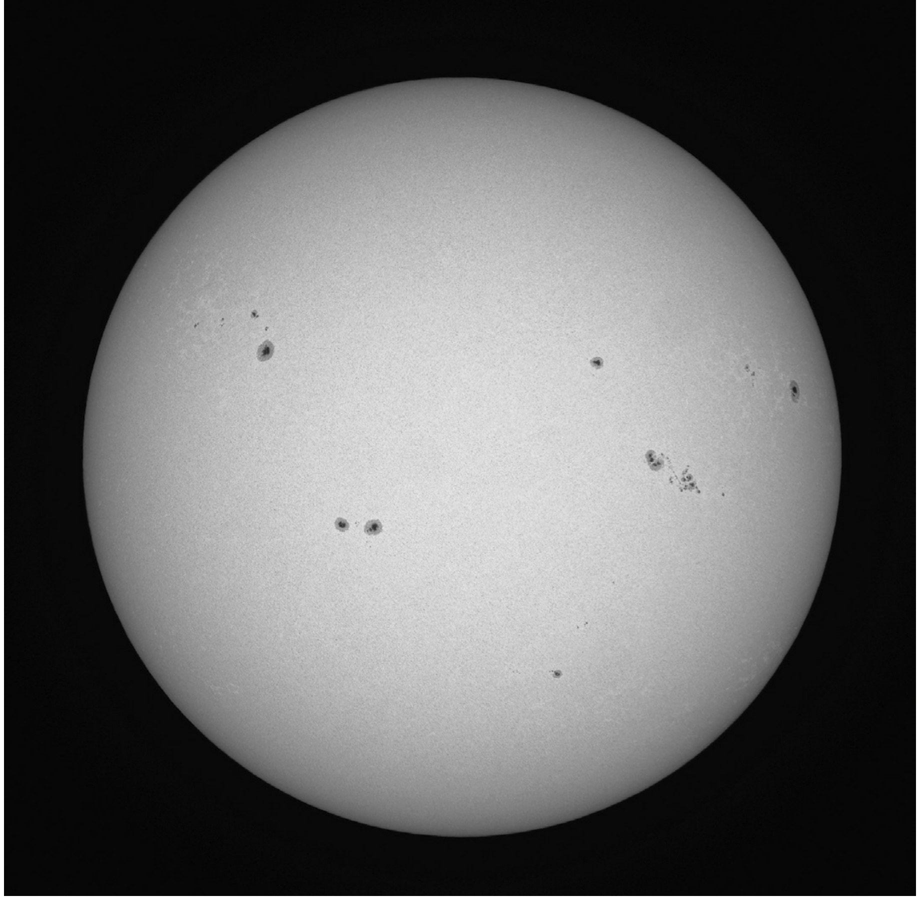
With its high quantum efficiency and very low read noise, this camera really excels at short exposure, deep-sky image stacking, or "live stacking" (*S&T:* May 2023, p. 60). It also works great for longer exposures, with a deep well capacity of just over 70,000 electrons, and has virtually non-existent dark current when cooled sufficiently.

I did much of my testing with fairly short individual exposures. The sensor has two readout modes: "normal" and "low noise." Compared to the "normal" setting, the "low-noise" mode slows the data readout from the detector slightly in order to reduce read-noise levels. Another setting that affects camera read noise is *gain*. Typically, increasing the gain reduces the read noise but at the expense of dynamic range. All Player One Astronomy cameras have a "High Conversion Gain" setting, in which the read noise drops significantly while still maintaining a reasonable amount of dynamic range.

This low noise profile and the chips' 91% quantum efficiency are an amazing combination. With it I was able to record galaxies from my fairly light-polluted backyard outside of Orlando, Florida, by stacking 1-minute luminance or RGB filtered images. The Leo Triplet (M65, M66, and NGC 3628) came out quite well, though I couldn't pick up the star stream extending from NGC 3628 even with many hours of one-minute exposures. That feature definitely needs darker skies than my backyard affords.

Longer exposures were never a problem either. I took dozens of 5-minute exposures of Sharpless 2-308, the Dolphin Nebula, in Canis Major at the Winter Star Party through a 3-nanometer O-III filter on a Sky-Watcher Esprit 150 refractor operating at f/7. There was no hint of the amp glow that plagued early CMOS cameras, or of other pattern noise.

I used *PixInsight* to measure and compare the mean pixel values of a bias frame with 5- and 10-minute dark exposures, all with the cooling set for –10°C. The values were 202.1, 202.5, and 202.7 units, respectively — dark current is detectable but negligible for all intents and purposes. Even the 10-minute exposure showed no traces of amp glow or similar artifacts.



▲ The Poseidon-M PRO can also be used for photographing the Sun, Moon, and even the planets. This full-disk solar image was recorded at 15 frames per second using an Astro-Physics 92-mm refractor and an Altair Astro Herschel Wedge (reviewed in the March issue, p. 68).

The exceptionally clean images are likely attributable to Player One's proprietary dead-pixel suppression (DPS) technology. This internal process eliminates dead pixels or hot pixels by replacing them with an average value of adjacent pixels, much like some post-processing software does with a bad pixel map. A company representative told me the DPS pattern is a static map captured as part of the camera's quantitative analysis process. Over time, this static map will need to be updated.

One feature I greatly appreciated with the Poseidon-M PRO is that its sensor chamber window includes a dew heater. I live in a high-humidity climate where it's common for a cooled camera to develop condensation on the sensor's protective window. As such, I consider this feature a "must have." Users adjust the heater setting through camera-control software, to work with local conditions.

Speaking of condensation control, I couldn't find anything on the company's website about the internal sensor chamber's moisture mitigation, so I emailed Sean Wang, CEO of Player One Astronomy. He told me the chamber is sealed but contains a strong desiccant that should last for years. In time, he said, the company would have a product available for users to replenish this themselves (and it *will* eventually need refreshing).

Thanks to its low noise and trouble-free operation, I feel the Poseidon-M PRO is a high-quality, solid performer for monochrome imaging with filters. I consider it a top choice for both beginners stepping up to their first dedicated astronomy camera and for seasoned imagers seeking a worthy upgrade.

■ Contributing Editor RICHARD WRIGHT is a software developer and lifelong amateur astronomer. He loves combining both interests on late nights and weekends.

◀ SELF-GUIDING CAMERA

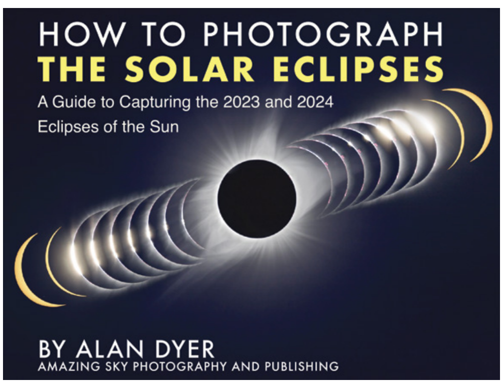
Chinese manufacturer ZWO recently announced a dual-sensor camera. The ASI2600MC Duo ($1,999) includes both an imaging sensor and a smaller autoguiding sensor that eliminate the need for additional guiding accessories. Its main imaging sensor is an APS-C-format, Sony IMX571 color CMOS detector with a 6,248 × 4,176 array of 3.76-micron-square pixels. The guiding chip is an SC2210 detector with a 1,920 × 1,080 array of 4-micron-square pixels. The camera's 16-bit camera boasts a quantum efficiency of 80% with a full-well capacity of 50,000e–. It can download 15 full-resolution frames per second, aided in part by a 512-megabyte DDR3 image buffer. The ASI2600MC Duo connects to your control computer via a USB 3.0 connection and also includes a 2-port USB hub for controlling additional accessories.

ZWO
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China
Phone: 0-51265923102; zwoastro.com

◀ SMART CAMERA

Dwarflab announces the DWARF II ($459), a smart camera that can image targets in the night sky as well as wildlife and sporting events. It uses an onboard neural-network processing unit to recognize and track the movement of your chosen target. The DWARF II contains two lenses and detectors: a 24-mm lens paired with a 2-megapixel detector and a 100-mm lens mated with an 8-megapixel Sony IMX415 color CMOS sensor for close-ups. The optics and internal electronics ride along in a compact housing that tracks in both altitude and azimuth. The DWARF II is controlled with a smartphone or tablet using the *DWARFLAB* app and connects via Wi-Fi or Bluetooth. Images are sent to your smart device, while uncompressed files are saved on a removable memory card. The device is powered by a replaceable, rechargeable battery. Each purchase includes a mini tripod, 64GB MicroSD card, a rechargeable battery, and a soft carry case.

Dwarflab
dwarflab.com



◀ ECLIPSE PHOTOGRAPHY HOW-TO

Sky & Telescope Contributing Editor Alan Dyer has published a downloadable ebook aimed at the budding eclipse photographer. *How to Photograph the Solar Eclipses* ($10.99 US) provides detailed advice and instruction for capturing solar eclipses using a variety of techniques. Dyer covers a wide range of options, from grabbing wide-field images with smartphones to shooting HDR composites through telephoto lenses and telescopes. The ebook provides tips for choosing all the equipment necessary for eclipse photography in 12 chapters. An entire chapter is dedicated to what can go wrong and how to avoid the most common mistakes. It's available from the Apple Books store, or as a downloadable PDF file readable on any operating system.

Amazing Sky
www.amazingsky.com/EclipseBook

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.*

Build a Solar Projector

Here's a solar viewer everyone can enjoy at once.

Ed Jones's 7-inch solar projector focuses its image 125 feet away, where it spans 14 inches.

DURING THE TOTAL SOLAR ECLIPSE next April, just about every place in Mexico and North America will see at least a partial phase. Wouldn't it be neat to share the view with a big group of your friends? Easy-peasy. Professional optician Ed Jones says, "Nothing shows an eclipse's partial phases better than a solar projector."

A solar projector is nothing more than a very-long-focal-length, single-objective lens with a mirror bouncing sunlight through the lens onto a white screen. Ed has built several of them in sizes ranging from 4 to 7 inches of aperture, and if you're the least bit comfortable grinding mirrors, you can do the same.

Only you won't be grinding a mirror this time unless you want to make your own flat. (You can use an ordinary Newtonian secondary for that.) For this project, you'll be grinding a lens.

Most people cringe at the thought of grinding a lens, but a solar-projector lens is probably the easiest lens you'll ever make. For one thing, the amount of curvature required is minuscule. We're talking a sagitta of only 0.002″ for a 4″-diameter lens. That's about half the thickness of a sheet of paper. It's so minuscule a curve that you can start your grinding with 40-micron grit, or even 20 if you don't mind hogging it out for a few minutes. (That's right: minutes.)

What should you use for a blank and a tool? Ordinary window glass will do. A piece with ¼″ thickness will work, but ⅜″ thickness would be ideal if you can find it. (And you can at Glass Cages [**glasscages.com**]. Get the low-iron glass; it's clearer.) Grind some channels in the tool to prevent seizing onto the lens and then get to work. Remember, you want the tool to be concave and the lens to be convex, so work with the tool on top.

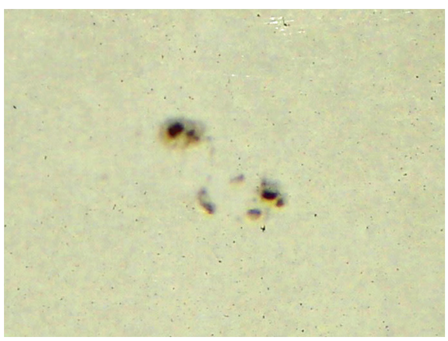
Window glass probably isn't flat enough to make a plano-convex mirror, so grind both sides. The thing about this lens is that you really don't need to hit any tight marks on focal length. Whatever you get will work fine so long as it's greater than about f/100 or so.

No kidding! The longer the focal length, the larger the focused image. Because the Sun subtends 32 arcminutes in the sky, the image size is simply the sine of 32 arcminutes (0.0093) times the focal length of the lens, so a 72-foot focal length (f/216 for a 4″ lens) would give you an 8″-diameter image.

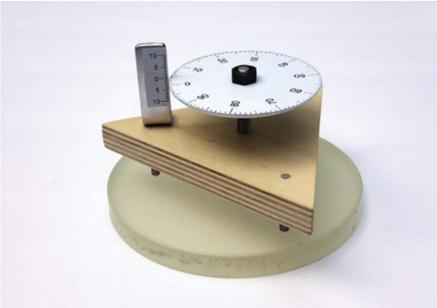
At that focal length, chromatic aberration isn't an issue, and the figure of your lens can remain spherical. You can use a simple spherometer to get close enough to the right curve, then move on to your fine grits and pitch polishing.

To test your lens, you can simply assemble the projector and look at the solar image. Is it good enough to show

▼ *Left:* The image of the Sun reveals details within sunspots and will be great for watching the partial phases of an eclipse. *Right:* The tracking mechanism prevents having to adjust the aim every couple of minutes. The mount isn't polar-aligned, but rather is aligned with its base along the path of solar motion across the sky.



ED JONES (3)



▲ A simple spherometer will get you close enough to the right curve. Look for how to build this spherometer, based on Ed Jones's design, in a future column.

small sunspots? If so, you're done. If not, you can simply keep polishing until both faces are adequately spherical.

The lens and mirror need a framework to hold them in place. The Sun moves across the sky, so unless you want to keep running back and forth to adjust the projector's angle, the mirror needs to be moveable to track it. A picture is worth a thousand words, so I'll just refer you to the photo of Ed's projector on the facing page. You can see that his mirror can move on two axes for alignment, and he's got a tracking mechanism that keeps the sunlight aimed through the lens at the distant screen.

The tracking mechanism is just a short arc of Delrin with threads tapped into it, with a threaded rod pulling the arc along at the end of an arm. The length of the arm determines the motor speed. Perhaps surprisingly, the mount isn't polar-aligned. Instead, since the Sun only deviates slowly from a straight line across the sky, Ed uses a tilting tripod head to align the base of the projector parallel to the Sun's path, and the motor drive moves the mirror at half the solar rate (because the reflection doubles the effect of changing the mirror's angle).

Ed's projector provides an excellent view of the Sun, and, with a little care, yours will too. During the upcoming eclipse, you'll have the most popular view at the party.

For more information, contact Ed Jones at **opticsed@gmail.com**.

JERRY OLTION

■ Contributing Editor **JERRY OLTION** is making a 4-inch version of this projector.

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Marvel, Executive Officer, 1667 K Street NW, Suite 800, Washington, DC 20006. 11. Known bondholders, mortgages, and other security holders owning or holding 1 percent of more of total amount of bonds, mortgages or other securities: None. 12. Tax status: Has Not Changed During Preceding 12 Months. 13. Publication title: SKY & TELESCOPE. 14. Issue date for circulation data below: October 2023. 15. The extent and nature of circulation: A. Total number of copies printed (Net press run). Average number of copies each issue during preceding 12 months: 43,868. Actual number of copies of single issue published nearest to filing date: 42,678. B. Paid circulation. 1. Mailed outside-county paid subscriptions. Average number of copies each issue during the preceding 12 months: 31,702. Actual number of copies of single issue published nearest to filing date: 30,494. 2. Mailed in-county paid subscriptions. Average number of copies each issue during the preceding 12 months: 0. Actual number of copies of single issue published nearest to filing date:0. 3. Sales through dealers and carriers, street vendors and counter sales. Average number of copies each issue during the preceding 12 months: 3,380. Actual number of copies of single issue published nearest to filing date: 2,894. 4. Paid distribution through other classes mailed through the USPS. Average number of copies each issue during the preceding 12 months: 0. Actual number of copies of single issue published nearest to filing date: 0. C. Total paid distribution. Average number of copies each issue during preceding 12 months: 35,082. Actual number of copies of single issue published nearest to filing date: 33,388. D. Free or nominal rate distribution (by mail and outside mail). 1. Free or nominal Outside-County. Average number of copies each issue during the preceding 12 months: 0. Number of copies of single issue published nearest to filing date: 0. 2. Free or nominal rate in-county copies. Average number of copies each issue during the preceding 12 months: 0. Number of copies of single issue published nearest to filing date: 0. 3. Free or nominal rate copies mailed at other Classes through the USPS. Average number of copies each issue during preceding 12 months: 0. Number of copies of single issue published nearest to filing date: 0. 4. Free or nominal rate distribution outside the mail. Average number of copies each issue during preceding 12 months: 0. Number of copies of single issue published nearest to filing date: 0. E. Total free or nominal rate distribution. Average number of copies each issue during preceding 12 months: 0. Actual number of copies of single issue published nearest to filing date: 0. F. Total free distribution (sum of 15c and 15e). Average number of copies each issue during preceding 12 months: 35,082. Actual number of copies of single issue published nearest to filing date: 33,388. G. Copies not Distributed. Average number of copies each issue during preceding 12 months: 8,786. Actual number of copies of single issue published nearest to filing date: 9,290. H. Total (sum of 15f and 15g). Average number of copies each issue during preceding 12 months: 43,868. Actual number of copies of single issue published nearest to filing: 42,678. I. Percent paid. Average percent of copies paid for the preceding 12 months: 100.0% Actual percent of copies paid for the preceding 12 months: 100.0% 16. Electronic Copy Circulation: A. Paid Electronic Copies. Average number of copies each issue during preceding 12 months: 14,105. Actual number of copies of single issue published nearest to filing date: 14,627. B. Total Paid Print Copies (Line 15c) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 49,186. Actual number of copies of single issue published nearest to filing date: 48,015. C. Total Print Distribution (Line 15f) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 49,186. Actual number of copies of single issue published nearest to filing date: 48,015. D. Percent Paid (Both Print & Electronic Copies) (16b divided by 16c x 100). Average number of copies each issue during preceding 12 months: 100.0%. Actual number of copies of single issue published nearest to filing date: 100.0%. I certify that 50% of all distributed copies (electronic and print) are paid above nominal price: Yes. Report circulation on PS Form 3526-X worksheet. 17. Publication of statement of ownership will be printed in the Dec '23 issue of the publication. 18. Signature and title of editor, publisher, business manager, or owner: Peter Tyson, Editor-in-Chief. I certify that all information furnished on this form is true and complete. 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What Is a Parsec?

ONE OF THE MOST NOTORIOUSLY challenging aspects of astronomy is determining distances to faraway celestial objects. There's no way for us to take a cosmic tape measure and trot along to a nearby star to see how far it is, as we would, say, if we're laying out the track for a 100-meter race. There is no direct way to determine distances to the planets, stars, and galaxies — if we want to know how far they are we need to do use an indirect method. (See page 12 of the October 2022 issue of *Sky & Telescope* for a whole article on celestial distance determination and its challenges.)

We may very well ask why it's important to know how far away things are. Well, to begin with, it's natural curiosity to want to know our place in the universe. Scientists have been tackling this issue all the way back to Aristarchus of Samos, who in the 3rd century BC tried to figure out the sizes and relative distances between Earth, the Moon, and the Sun. He used observations of the first- and last-quarter Moon combined with some geometry and math to determine that the Sun was 19 times farther than the Moon. He was off by a lot (it's in fact some 390 times more distant), but his approach was revolutionary.

When we look up at the night sky, some stars look brighter than others. But are they *truly* brighter, or is it just a consequence of how close they are? If all stars were of the same intrinsic brightness, then we might assume that dimmer stars are farther than brighter ones. But that's not the case — a luminous star far away might look as bright as a dimmer star nearby. And, it was only once we understood that stars lie at different distances that we began to better understand their true nature.

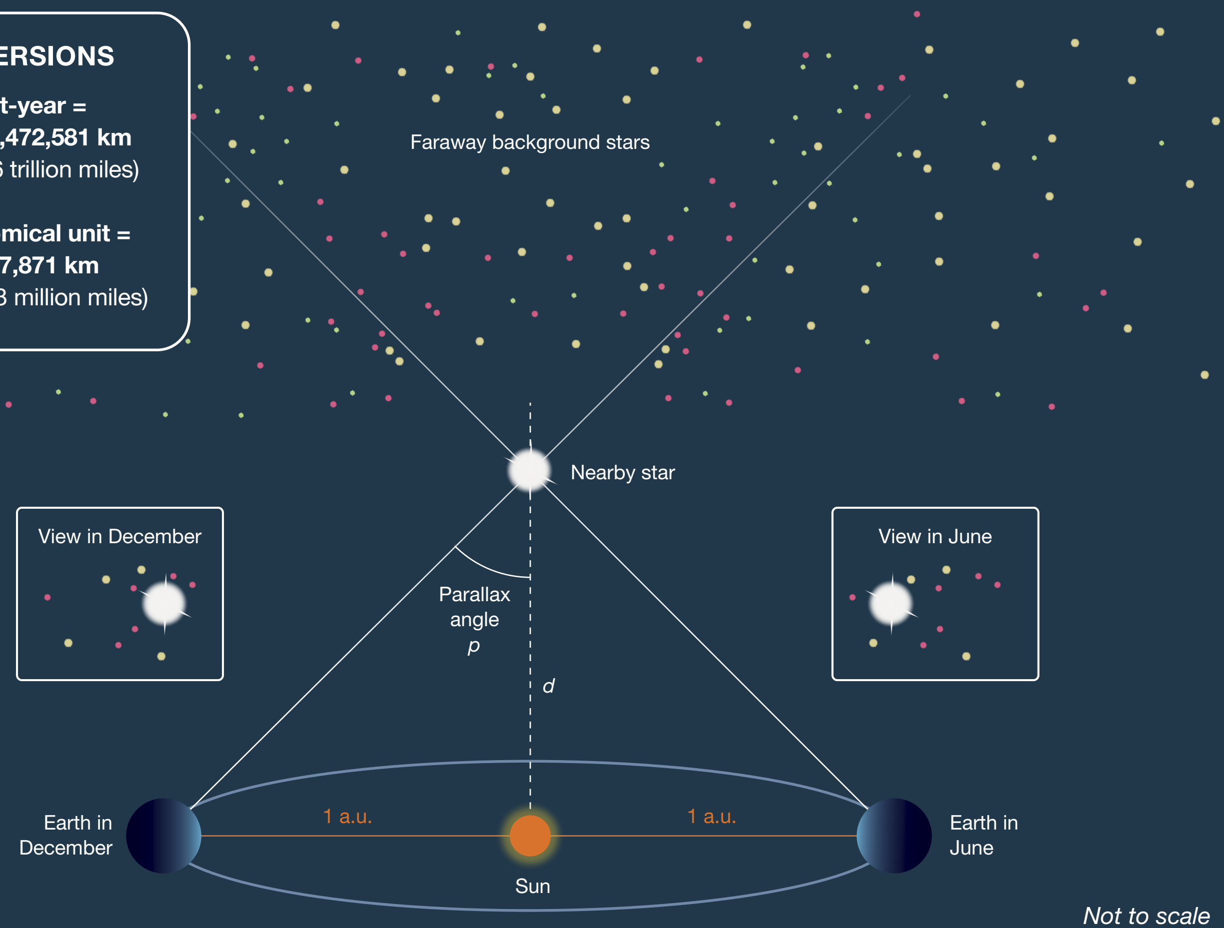
As a reader of this magazine, you'll notice that we largely express distances to celestial objects in terms of *light-years*, i.e., the distance that light travels in one year. We also use the *astronomical unit* (abbreviated to a.u.), which is the average distance between Earth and the Sun. However, there's another unit of distance that we sometimes bandy about (and which is favored by professional astronomers) and that is the *parsec*.

Before we discuss the parsec, let's first touch upon *parallax*.

CONVERSIONS

1 light-year = 9,460,730,472,581 km
(or nearly 6 trillion miles)

1 astronomical unit = 149,597,871 km
(or nearly 93 million miles)



BEATRIZ INGLESSIS / S&T; SOURCE: ESA

From Parallax . . .

How did we first start understanding how far away celestial objects are in the local universe? Quite straightforwardly, in fact — expanding on a familiar phenomenon, *stereoscopic vision*.

If you're standing, say, in a field of sunflowers and looking at a distant copse, you'll notice that if you close one eye, open it, then close the other eye that the image of the clump of trees doesn't move very much against the more distant, stationary landscape. But now crouch down in the field and do the same with a nearby sunflower. You'll notice the sunflower *appears* to move way more (than the copse) against the background. The apparent shift of a foreground object against a backdrop farther away is known as *parallax*.

This phenomenon happens because our eyes are side by side — they give us the perspective we need to gauge distances. But it only works for relatively nearby objects — our eyes are too close together for the effect to be useful for larger distances. In other words, the *baseline* of our two eyes is very short.

But imagine if we could extend the distance between our eyes. Obviously we can't do that, but we do have a very useful tool to hand: Earth's orbit around the Sun. If we substitute telescopes for our eyes and point them at a celestial target at six-month intervals, we have a baseline that's equivalent to twice the distance of Earth from the Sun. Now we're talking!

. . . to Parsec

To measure parallax, we need Earth orbiting the Sun (check), a target (pick your favorite object), distant background stars (there are many!), and a telescope with which to make the measurements. Follow along with the diagram at left.

Observations of a nearby object taken six months apart will show that its position shifts against faraway background stars (that appear stationary) by a certain angle, the stellar parallax. Half that angle helps us measure the star's distance from the Sun using a very simple equation.

The diagram shows a right triangle with adjacent sides formed by the distance between Earth and the Sun as well as the distance between the Sun and the target star. The parallax is the angle between them. So, applying high-school trigonometry we have:

$$\tan(p) = \frac{1 \text{ a.u.}}{d}$$

(Remember that? The tangent of an angle equals the opposite side divided by the adjacent side.)

Rearranging yields:

$$d = \frac{1 \text{ a.u.}}{\tan(p)}$$

For very small angles, the formula simplifies to:

$$d = 1/p$$

If an object's position on the sky appears to shift by an angle, *p*, of 1 arcsecond when observed over a baseline of 1 a.u., then the object lies at a distance, *d*, of 206,265 a.u., or 3.26 light-years. And voilà, we have the definition and value for the parsec — which is a portmanteau for *parallax of one second*.

The table lists parallaxes (in milliarcseconds) and distances (in both parsecs and light-years) for a selection of stars. Note that we're indeed dealing with very small angles — and that the smaller the angle, the farther the object.

Star	*p* (mas)	*d* (pc)	*d* (l-y)
Sirius	379	2.66	8.68
Pollux	96.5	10.4	33.9
Castor	63.3	15.8	51.5
Aldebaran	48.9	20.4	66.5
Betelgeuse	6.55	153	499
Rigel	3.78	265	864

So long as we can measure the parallactic angle of an object, we can derive its distance. And, until we can find a way to stretch out our cosmic tape measure, our parallax estimates will have to do! ■

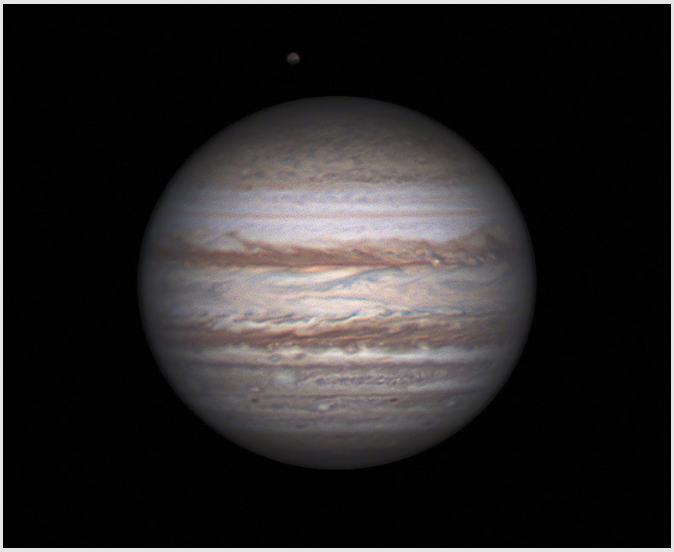
The subdivisions of degrees we call *minutes of arc* (or *arcminutes*) and *seconds of arc* (or *arcseconds*) date back to the ancient Babylonian astronomers and are units for measuring celestial angles. Nothing to do with the minutes and seconds that we use to keep time, they nevertheless break down in a similar fashion:

1 degree (°) = 60 arcminutes (′)

1 arcminute = 60 arcseconds (″)

So... 1° = 3,600″

DUSTY SHARK
Vikas Chander
Dark nebula LDN 1235 in Cepheus is a swath of dust some 670 light-years from Earth. Spiral galaxy UGC 11861 (right) resides about 60 million light-years farther in the background yet shines through the intervening gas and dust.
DETAILS: *Takahashi Epsilon E-180 astrograph and ZWO ASI 2400MC Pro camera. Total exposure: 13.5 hours through RGB and narrowband filters.*



△ PARTIAL ECLIPSE OF CALLISTO

Oleg Bouevitch

Jupiter's North and South Equatorial Belts were particularly turbulent on the evening of September 30, 2022. Just above Jupiter's north pole, Callisto is seen drifting through the gas giant's shadow, so only its northern hemisphere is visible.

DETAILS: *14-inch Schmidt-Cassegrain and ZWO ASI290MM camera. Stack of several frames through RGB filters.*

△△ STARBURST RING

Dave Doctor

A wispy ring of young, massive stars surrounds the spiral galaxy M94 in Canes Venatici. Several dark dust lanes and regions of reddish star formation extend outward from the galaxy's compact nucleus.

DETAILS: *Officina Stellare RiDK 400 telescope with SBIG STX-16803 camera. Total exposure: 33 hours through LRGB filters.*

▷ GALACTIC TRIO

Mario Motta

Arp 286 is a trio of spiral galaxies almost 90 million light-years away in Virgo. Gravitational interactions with NGC 5566 (bottom) have stretched out the arms of NGC 5560 (right), while NGC 5569 (top left) appears relatively unaffected.

DETAILS: *32-inch home-built relay telescope and ZWO ASI6200 camera. Total exposure: 3.5 hours through LRGB filters.*

▽ ISLAND LIGHT SHOW

Barry Burgess

On August 13th, several Perseid meteors cut across the sky above the coast of the Aspotogan Peninsula in Nova Scotia, Canada.

DETAILS: *Canon 6D camera with Rokinon 20-mm lens. Total exposure: 1 minute at f/1.8, ISO 1600.*

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Caught Unawares

While giving a companion a celestial tour aboard ship one night, the author had no idea how many others he was captivating.

MANY, IF NOT MOST, amateur astronomers have jobs unrelated to astronomy. It's almost as if their working hours are spent in a different world than the one they inhabit when out under the stars. They're surrounded by a separate circle of associates and even speak a distinct sort of language.

Seldom do these two disparate worlds intersect, but when they unexpectedly converge, it can be a surprisingly rewarding experience. I enjoyed one of these rare moments on a September evening in 2001.

My day job back then was as a contract technician providing support for shipboard guided-missile launchers for the U.S. Navy. My assignment that day involved riding a ship on an overnight assessment. I was a member of a team conducting an INSURV (Inspection and Survey) on the USS *Kauffman*, a Perry-class guided-missile frigate based in Norfolk, Virginia.

After dinner that evening, a teammate and I strolled out onto the helicopter flight deck to get some air. It was a pleasant eve with calm seas and clear skies. We were miles off the North Carolina coast, with only the ship's navigation lights to compete with the emerging stars as twilight faded.

My associate knew I was an amateur astronomer but had only a vague understanding of what that meant. I suppose it was to test me, as much as anything else, when he asked me to identify the "star" that was brightening in the southern sky. When I told him it wasn't a star but the planet Mars, it piqued his curiosity.

I directed his gaze higher up and pointed out the Summer Triangle. I explained how its three bright stars — Vega, Deneb, and Altair — belong to three different constellations. When Antares rose, I asked him to compare its ruddy color to Mars, noting that the name *Antares* comes from ancient Greek and means "rival of Mars."

When the Big Dipper came into view, I showed my companion how to follow the arc of the dipper's handle to Arcturus and then on to Spica, and mentioned how the two stars at the top of the bowl are known as the Pointers. He was able to deduce that they point to Polaris, the North Star.

Soon the Milky Way materialized. The Teapot asterism in Sagittarius became obvious, as did the stars of the Scorpion. I remarked how Cygnus the Swan seems to be flying down the Milky Way, leaving a dark rift below its wings. I showed him how the W of Cassiopeia can direct the way to M31, the Andromeda Galaxy, which was already visible to our unaided eyes. We were even able to discern the Great Globular Cluster M13 in Hercules.

It was then I realized that a group had silently gathered behind us. Twenty or more ship riders and crew had become celestial tourists. They stood transfixed, gazing upward without making a sound. They'd apparently been listening the whole time. My two worlds had merged.

The moment passed — it was time to go back inside and return to work. But I often wonder if that impromptu lecture sparked anything. Did I inspire someone with that visit to my other world? I'd like to think I did.

■ Contributing Editor **TED FORTE** enjoys astronomy outreach the most when it's unplanned.

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